RRP

MATERIAL PRESENTED BY
the
JET PROPULSION LABORATORY
at the
ANNUAL OART RESEARCH PROGRAM REVIEW
October 11 - 12, 1965

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

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JET PROPULSION LABORATORY
Pasadena, California

AGENDA

OART RESEARCH PROGRAM REVIEW

PROPULSION DIVISION (38)

RESEARCH & ADVANCED CONCEPTS SECTION - 383

- FLUID PHYSICS -

October 11, 1965
Bldg. 180 - Room 101

8:30 a.m.	Introductory Remarks		D. R. Bartz
8:40	Fluid Dynamic Investigation of Vortex Flows	129-01-11-01	P. F. Massier
8:55	Convective Heat Transfer in Accelerating and Decelerating Flows	129-01-12-01	Dr. L. H. Back
9:30	Plasma Heat Transfer	129-01-09-04	P. F. Massier
10:00	Nonequilibrium Flow in MHD Generators and Accelerators	129-01-04-01	G. R. Russell
10:25	Break		
10:40	Electron Recombination; Shock Wave Structure; Laser Diagnostics	129-01-05-04 129-01-07-01	Dr. C. J. Chen
11:05	Microwave Diagnostics; Electron Attachment with Electrophilic Gases	129-01-07-01 129-01-05-04	Dr. A. J. Kelly
11:35	Shock Tube Magnetic Probe Velocity Measurements; Spectroscopic Studies in a MPD Arc	129-01-07-01 129-01-04-01	Dr. N. M. Nerheim

AGENDA

OART RESEARCH PROGRAM REVIEW

GUIDANCE & CONTROL DIVISION (34)

GUIDANCE & CONTROL RESEARCH SECTION

October 11, 1965
Bldg. 180 - Room 101

1:00 p.m.	Introductory Remarks	J. R. Scull N. Sirri
1:15	Optical Physics Research 129-02-05-01	
	Electro-Optic Effect in Barium Titanate	Dr. A. R. Johnston
	Second Harmonic Production in Barium Titanate	M. S. Shumate
	Photoconductive Thin Films	Dr. R. Ueda
2:20	Thermionics Research 129-02-01-07	
	Oscillations in Thermionic Diodes	Dr. K. Shimada
2:45	Magnetics and Thermoelectrics Research 129-02-05-06	
	Magnetic Interaction by NMR Techniques	Dr. D. I. Tchernev
	Thermoelectric Thin Films	Dr. D. S. Herman
3:30	Break	
3:45	Cryogenics Research 129-02-05-02	
	Cryogenic Gyroscope	N. Sirri
	Velocity and Attenuation of Sound in Liquid Helium	Dr. W. M. Whitney
4:30	Semiconductor Research 129-02-05-09	
	Space-Charge-Limited Current in Solids	Dr. A. Shumka
	Titanium Oxide Thin Films	J. Maserjian
5:05	Adjourn	

AGENDA

OART RESEARCH PROGRAM REVIEW

SPACE SCIENCES DIVISION (32)

October 12, 1965
Bldg. 180 - Room 101

8:30 a.m.	Introductory Remarks		Dr. R. Meghreblian

FLUID PHYSICS

8:45	Molecular Spectroscopy 326	129-01-01-01	Dr. R. Poynter Dr. S. Trajmar
9:30	Continuum Fluid Dynamics 327	129-01-09-01	Dr. J. Kendall Dr. L. Mack Dr. F. Hama
10:00	Rarefied Gas Dynamics 327	129-01-10-01	Dr. D. Russell Dr. W. Christensen
10:30	Break		
10:45	Magneto Fluid Dynamics 327	129-01-05-02	Dr. T. Maxworthy
11:15	Shock Heated Plasmas and Jet Structures 327	129-01-05-03	Dr. R. Center Dr. H. Ashkenas

ELECTRO PHYSICS

1:00	Quantum Chemistry 326	129-02-03-04	Dr. M. Geller
1:30	Photochemistry 326	129-02-03-02	Dr. W. DeMore
2:00	Radiation Chemistry 326	129-02-03-06	Dr. J. King
2:30	Plasma Physics 327	129-02-03-03	Dr. A. Bratenahl
3:00	Break		
3:15	Low Temperature Physics 328	129-02-05-04	Dr. D. Elleman

October 12, 1965

3:45	Theoretical Physics 328	129-02-07-02	Dr. M. Saffren Dr. F. Estabrook Dr. C.-S. Wu
4:15	Nuclear Physics Research 328	129-02-03-08	Dr. B. Whitehead Dr. E. Haines

Resources Summary for OART - RR July 26, 1965

A. Program Totals

Manpower (man-years):	Actual FY '64	Actual FY '65	Actual FY '66
Professional	94.0	73.6	68.0
Other	51.3	43.1	39.5
Total	145.3	116.7	107.5
Dollars (in ooo's):			
Direct Labor and Overhead	3911	3689	3628
In-house support	1185	635	1008
Procurements	1304	1254	1169
Total	6400	5578	5805

B. Definitions:

1. Manpower: technical cognizant division only; excludes technical division services and administrative services.

2. Direct Labor and Overhead: salaries, wages and all burdens

3. In-house support: includes administrative services such as photography, reproductions and reports and plant engineering; technical division services such as design, instrumentation, computers, etc.; and in house fabrication and travel.

C. Subprogram Totals

1. Fluid Physics Research

	FY '64	FY '65	FY '66
a. Manpower (man years):			
Professional	29.3	22.3	21.1
Other	20.5	18.0	16.1
Total	49.8	40.3	37.2

b. Dollars (in 000's):

Direct Labor and Overhead	1320	1231	1187
In-house support	771	322	454
Procurements	461	390	193
Total	2552	1943	1834

2. Electro-Physics Research

	FY '64	FY '65	FY '66
a. Manpower (man-years):			
Professional	27.9	24.8	21.6
Other	11.0	9.8	10.6
Total	38.9	34.6	32.2
b. Dollars (in 000's)			
Direct Labor and Overhead	1095	1181	1163
In-house support	174	112	204
Procurements	300	465	487
Total	1569	1758	1854

3. Materials Research

	FY '64	FY '65	FY '66
a. Manpower (man-years):			
Professional	24.4	16.2	10.9
Other	18.8	14.7	11.6
Total	43.2	30.9	22.5
b. Dollars (in 000's):			
Direct Labor and Overhead	1090	885	710
In-house support	166	122	147
Procurements	512	367	487
Total	1768	1374	1344

4. Applied Mathematics

	FY '64	FY '65	FY '66
a. Manpower (man-years):			
Professional	12.4	10.3	14.4
Other	1.0	0.6	1.2
Total	13.4	10.9	15.6
b. Dollars (000's)			
Direct Labor and Overhead	406	392	568
In-house support	74	79	203
Procurements	31	32	2
Total	511	503	773

D. Interesting Statistics

1. Research Programs (in 000's)	FY '64	FY '65	FY '66
a. Direct labor and overhead	27.0	31.5	33.8
b. In-house support/man-year	8.2	5.4	9.4
c. Procurements/man-year	9.0	10.7	10.8
d. Total/man-year	44.2	47.6	54.0
e. In-house support/prof. man year	12.6	8.6	14.9
f. Procurements/prof. man-year	13.9	17.0	17.2
g. Total/prof. man-year	68.0	76.0	85.5
2. OART			
a. Direct labor and overhead/man-year		30.7	31.4
b. In-house support/man-year		12.3	15.1
c. Procurements/man-year		29.0	30.1
d. Total/man-year		72.0	76.6
e. In-house support/prof. man-year		21.5	25.0
f. Procurements/prof. man-year		50.5	49.7
g. Total/prof. man-year		125.4	126.5

JEC:sr

FLUID PHYSICS - DIVISION 38

TITLE NASA Code JPL Code	FISCAL YEAR	PROFESSIONAL MAN-YEARS	DOLLARS (in 000's)
Plasma Sources, Generators and Accelerators			
129-01-06-01	1964	2.0	300
329-11101-1-3830	1965	1.7	203
	1966	1.3	187
Plasma Transport Properties, Shock Waves, and Inelastic Rate Processes			
129-01-05-04	1964	1.0	125
329-11201-1-3830	1965	0.9	154
	1966	1.8	145
Plasma Diagnostics			
129-01-07-01	1964	1.5	175
	1965	0.6	119
	1966	1.4	155
Plasma Heat Transfer			
129-01-09-04	1964	2.5	300
	1965	1.7	226
	1966	3.5	325
Vortex Investigations			
129-01-11-01	1964	2.0	130
	1965	1.8	151
Heat Transfer in Accelerating and Decelerating Flows			
129-01-12-01	1964	1.0	120
329-10401-1-3830	1965	0.9	143
	1966	0.9	140

VORTEX INVESTIGATIONS
NASA Work Unit 129-01-11-01
JPL 329-11501-1-3831

A. GAS VORTEXES

The development of an optical instrument to be used for determining the transient mass flow rate of a high molecular weight gas in a mixture of high and low molecular weight gases discharging through the exit orifice of a vortex tube has been completed. The instrument was calibrated and used to measure the flow of Freon-13 (chlorotrifluoromethane) exhausting from the 4.50-in. diameter steel vortex tube. Experiments have been performed at various mass flow rates of hydrogen or nitrogen and Freon-13 in three basically different vortex tube configurations. The vortex type flows that can be generated in the laboratory retain about the same amount of heavy gas as would be expected if no diffusion were occurring. Because the gaseous-vortex-reactor concept requires a vortex type flow that can retain orders of magnitude more mass of heavy gas, it is concluded that a means must be found to generate a much higher strength vortex than is now possible.

Measurements of the mass of Freon-13 retained in the vortex tube compared to the mass that would be retained if no diffusion were occurring (diffusion coefficient $D_{LH} = 0$) are shown in Fig. 1. These measurements were made at four hydrogen mass flow rates, $\dot{m}_L$, and at each flow rate the Freon mass flow rate, $\dot{m}_H$, was varied between approximately 2 and 8% of $\dot{m}_L$. The significant features of Fig. 1 are that the retained mass ratio, $m/m_{D_{LH} = 0}$, is of order 1 and that no apparent trend is distinguishable as the hydrogen mass flow rate is varied.

The details of the distribution of Freon in a vortex type flow, as represented by the heavy-to-light gas mass density ratio, have been reported in a previous progress review. An example of those findings is shown in Fig. 2. If no diffusion had occurred, the density ratio, ρ_H/ρ_L, normalized with respect to itself at large radii, $(\rho_H/\rho_L)_\infty$, would have been constant with radius and equal to 1.0. Because this ratio is not constant, one can conclude that some diffusion does indeed occur. However, the alteration of the density ratio distribution appears to be a perturbation of the otherwise homogeneous binary flow and not the orders of magnitude change required by the gaseous-vortex-reactor concept.

Three technical reports have been written and are in the final stages of editing. The first covers the theoretical and experimental investigation of a binary vortex flow and includes the effects of inserting probes into this type of flow as determined by measuring the change in radial static pressure distribution. The second report covers the effects of mass flow rate and exit orifice diameter on the radial static pressure distribution in a nitrogen vortex flow. This report includes a comparison between the measured quantities and existing theories. The third report describes the mass retention measurements and summarizes the results of these measurements.

A technical report on similarity in confined, vortex flows has also been prepared. It is an attempt to determine (1) criteria by which vortex flows may be scaled and, also, (2) means by which experimental work of different investigators might be compared. The similarity model was derived from very simple considerations assuming a laminar, two-dimensional vortex flow. Experiments designed to

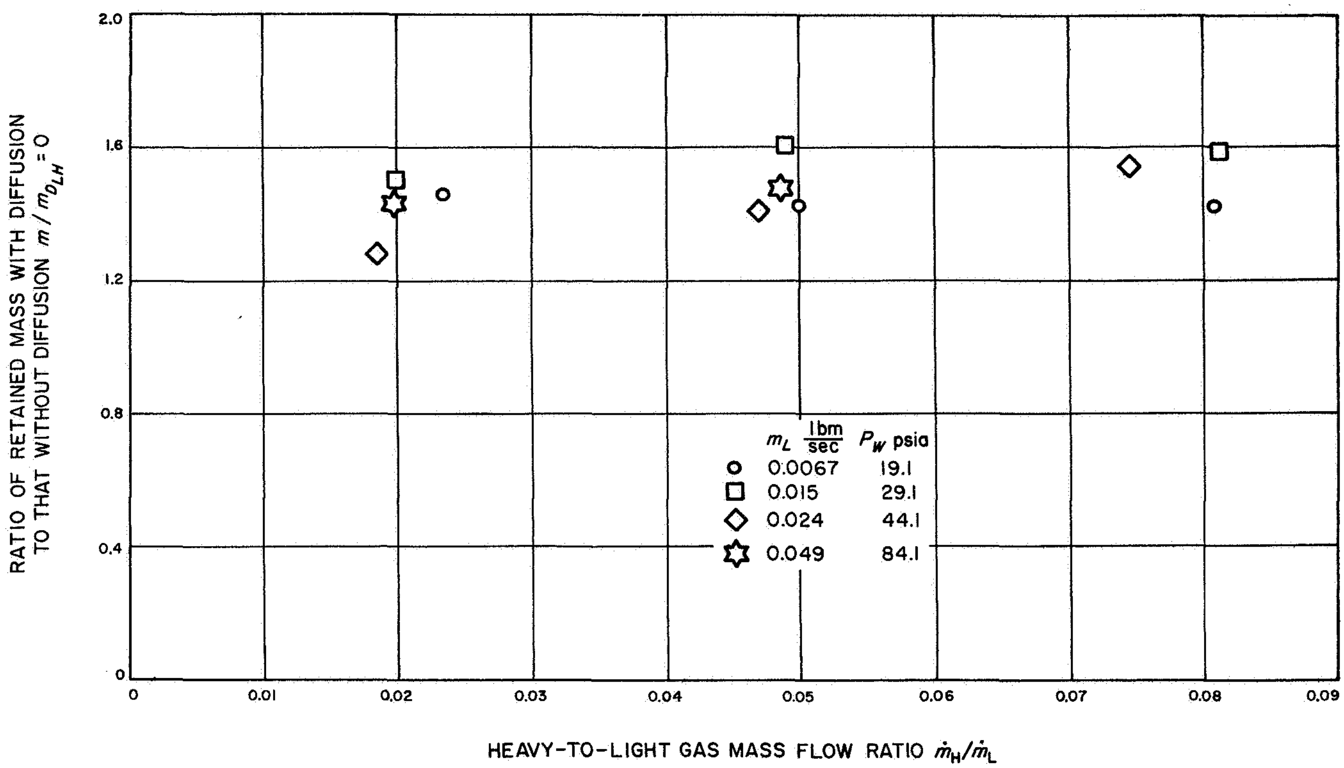


Fig. 1. Retained mass of heavy gas in binary vortex flow

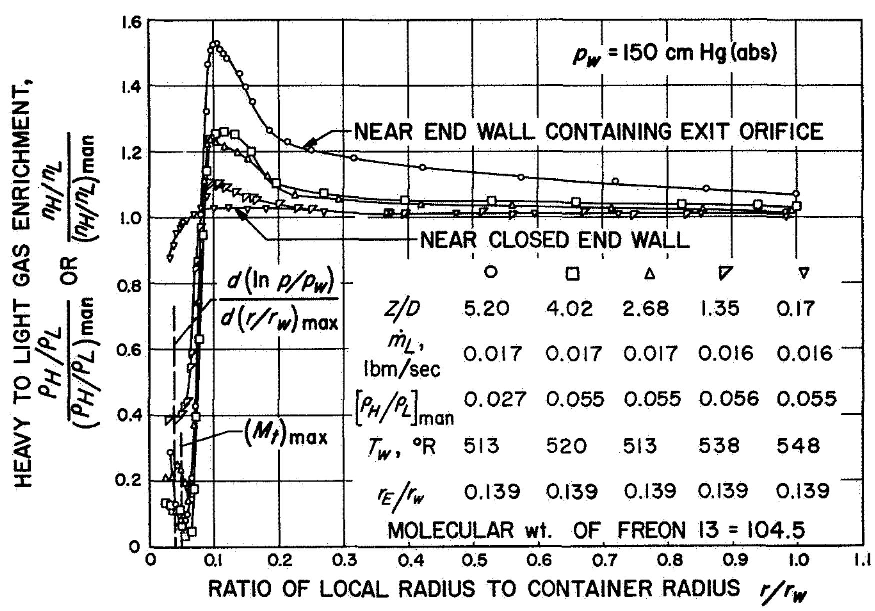
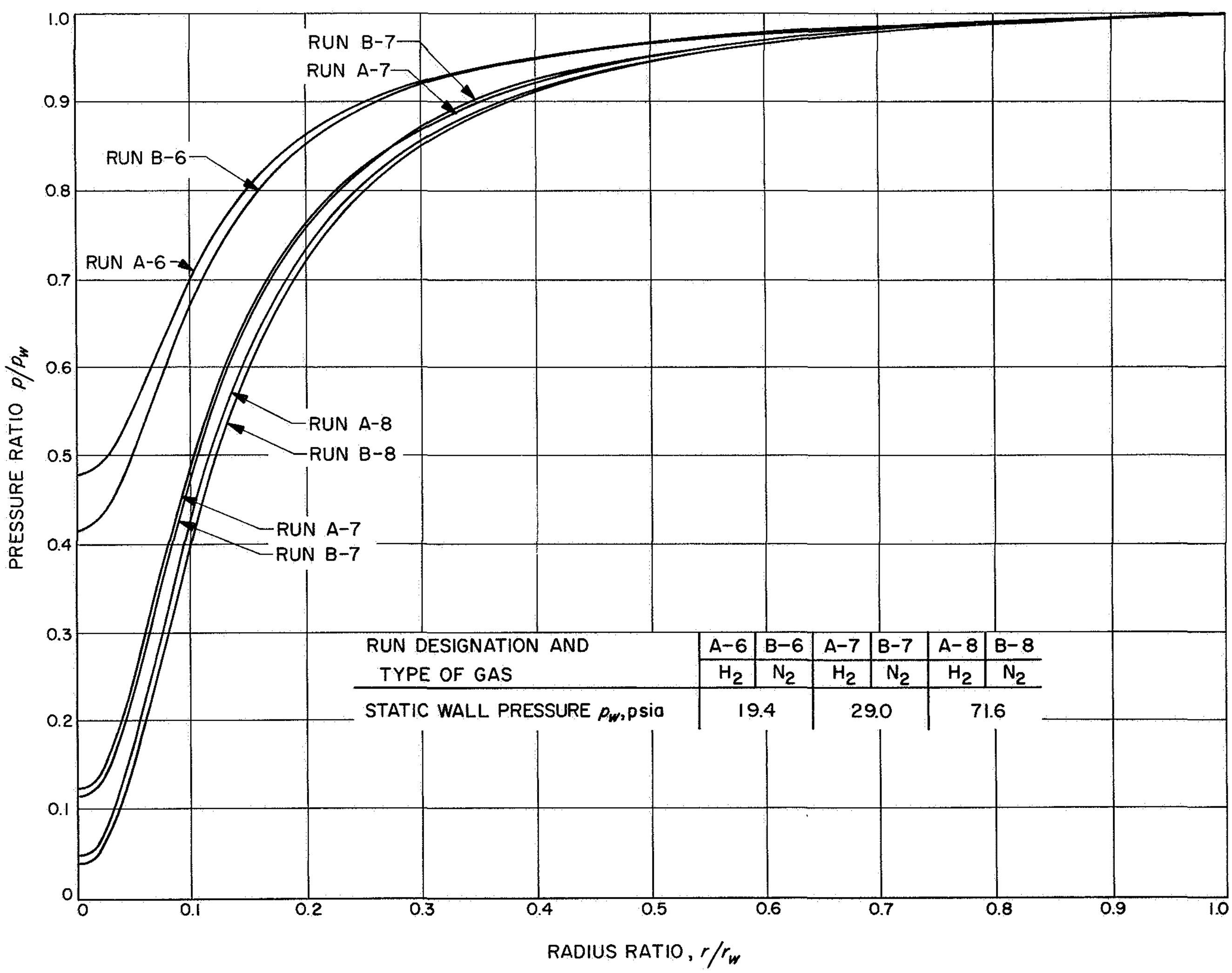


Fig. 2. Distributions of heavy-to-light gas mass density or concentration ratio in vortex containing mixture of hydrogen and Freon 13

test this theory were performed and indications are that the model is much too restrictive and not sufficiently realistic. These experiments were performed using gaseous nitrogen and gaseous hydrogen in separate tests in identically the same apparatus. Similarity conditions, as indicated by the model, were imposed on the tests that were then evaluated by comparing static end-wall pressure distributions. An interesting technique of obtaining similar end-wall pressure distributions was discovered, however, and this consisted of imposing the same static wall-pressure p_w on the two gases. Figure 3 shows the results of three such pairs of tests. This technique, which is not predicted by the theoretical model, nevertheless gave much better results.



RUN DESIGNATION AND TYPE OF GAS	A-6 H_2	B-6 N_2	A-7 H_2	B-7 N_2	A-8 H_2	B-8 N_2
STATIC WALL PRESSURE p_w, psia	19.4		29.0		71.6	

Fig. 3. Comparisons of pressure distributions between hydrogen and nitrogen run at equal values of static wall-pressure (Fig. 6, "similarity in confined vortex flows" E. J. Roschke, TR-32-789)

B. WATER VORTEXES

A Space Programs Summary has been written and released concerning the effects of aspect ratio on the flow in a confined, jet-driven vortex tube. This work summarizes some of the effects of vortex length to diameter ratio that were observed in a water vortex. Aspect ratio, in addition to the relative exit-hole size of the vortex and the mass rate of flow per unit vortex length, did markedly affect the end-wall static pressure distributions observed in the vortex. Figure 4 shows a typical result; the vortex static pressure drop between the cylindrical wall and the vortex center line has been normalized for the static pressure at the cylindrical wall and plotted as a function of aspect ratio for several values of wall pressure. Sometimes an air core was present in the vortex, as noted. Flow visualization studies by dye injection into this same vortex apparatus had previously given some indication that differences in flow-field structure did occur as aspect ratio was varied. For small L/D, where the vortex is probably dominated by end-wall boundary layer effects, the flow appeared to be laminar, well-ordered, and radially stratified; core size in the vortex was relatively large. At large L/D, the flow appeared to be turbulent (not well-ordered) except in thin shear regions near the core; the vortex core tended to decrease in diameter with increasing L/D. An attempt to portray these effects is shown in Fig. 5, a series of drawings at different L/D adapted from color photographs. The experimental work carried out on the water vortex is being written in the form of two separate technical reports. The first report, which contains the results of the quantitative portion of the program and deals particularly with end-wall static pressure distributions, is complete and now in preliminary editing process. The second report, which will contain the results of the qualitative portion of the program and particularly flow visualization results, is still in the process of preparation. This latter report has been delayed because of the need to view and assess over 8000 ft of color motion picture film.

C. FUTURE ACTIVITIES

As a consequence of the discouraging results obtained in the gas vortexes for the retention of the mass of the high molecular weight gas and the small amount of diffusion that occurred, it was decided to end the entire vortex project at the end of FY 1965. During the first half of FY 1965, however, one experiment will be performed on a transparent tube that has provision for swirling end-wall injection as well as peripheral injection, adjustable L/D, and independent means of fluid injection at nine different locations. The experiments to be performed primarily include the retention of smoke in gaseous nitrogen. This is anticipated to be a minor effort because the apparatus has been fabricated and installed on a test stand.

D. MEETINGS AND PRESENTATIONS

Dr. E. J. Roschke and Mr. T. J. Pivirotto presented the results of the binary gaseous and water vortexes before the NASA Research Advisory Committee on Fluid Dynamics at the Jet Propulsion Laboratory, May 6, 1965. Mr. T. J. Pivirotto attended the AIAA Propulsion Joint Specialist Conference at Colorado Springs, Colorado, June 14-18, 1965.

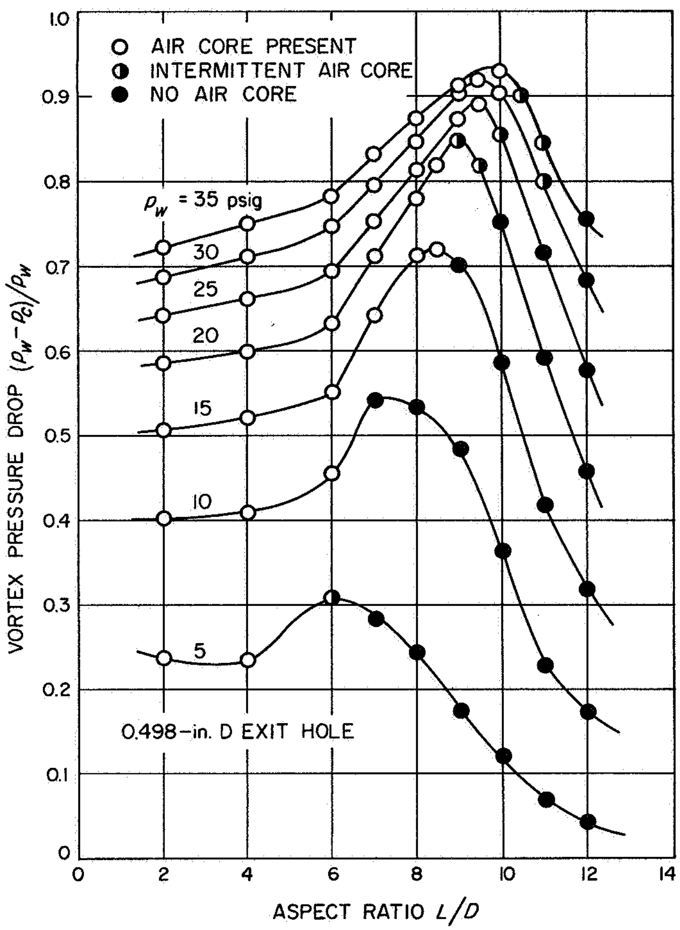


Fig. 4. Variation of vortex pressure drop with aspect ratio for various values of static wall pressure

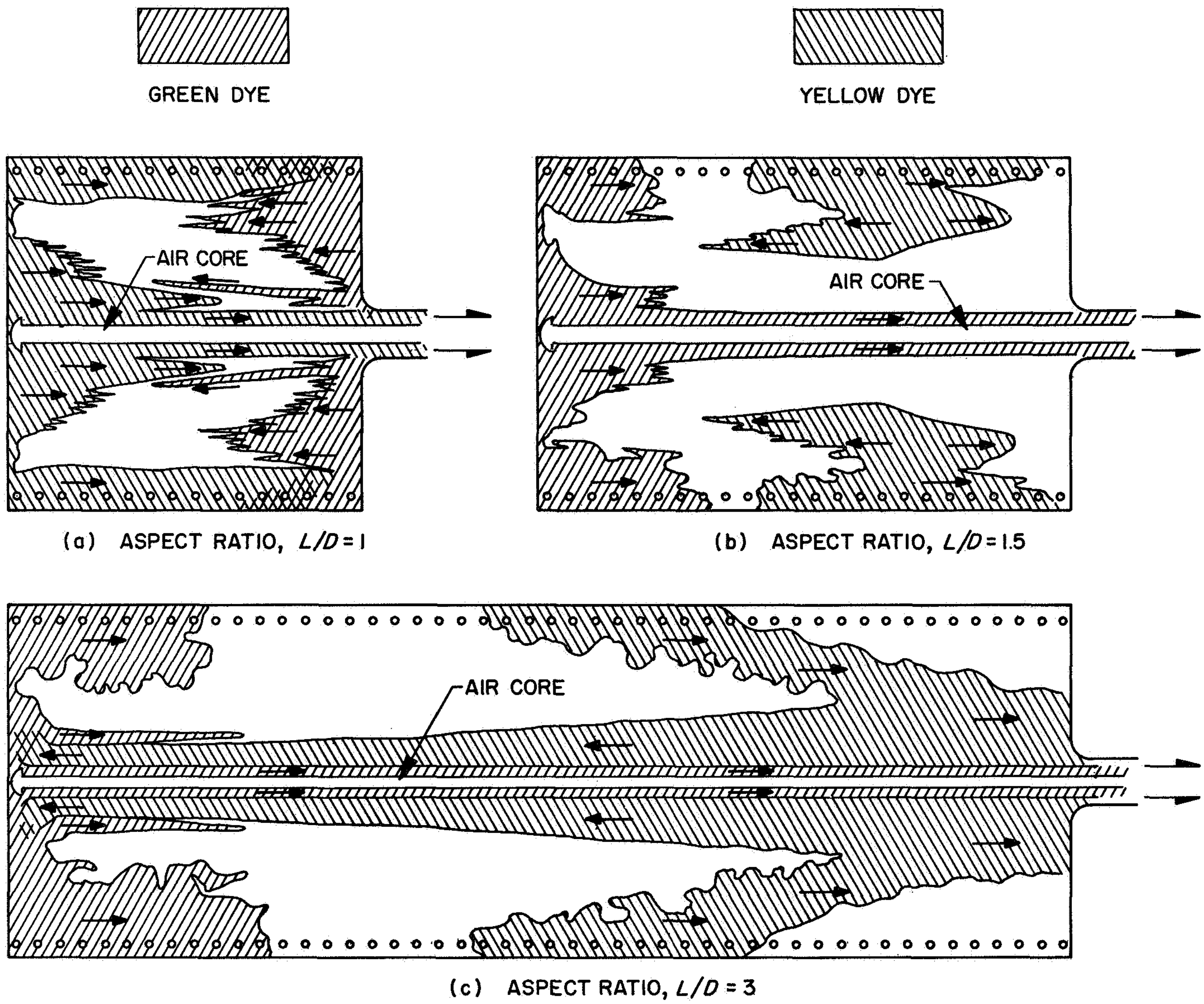
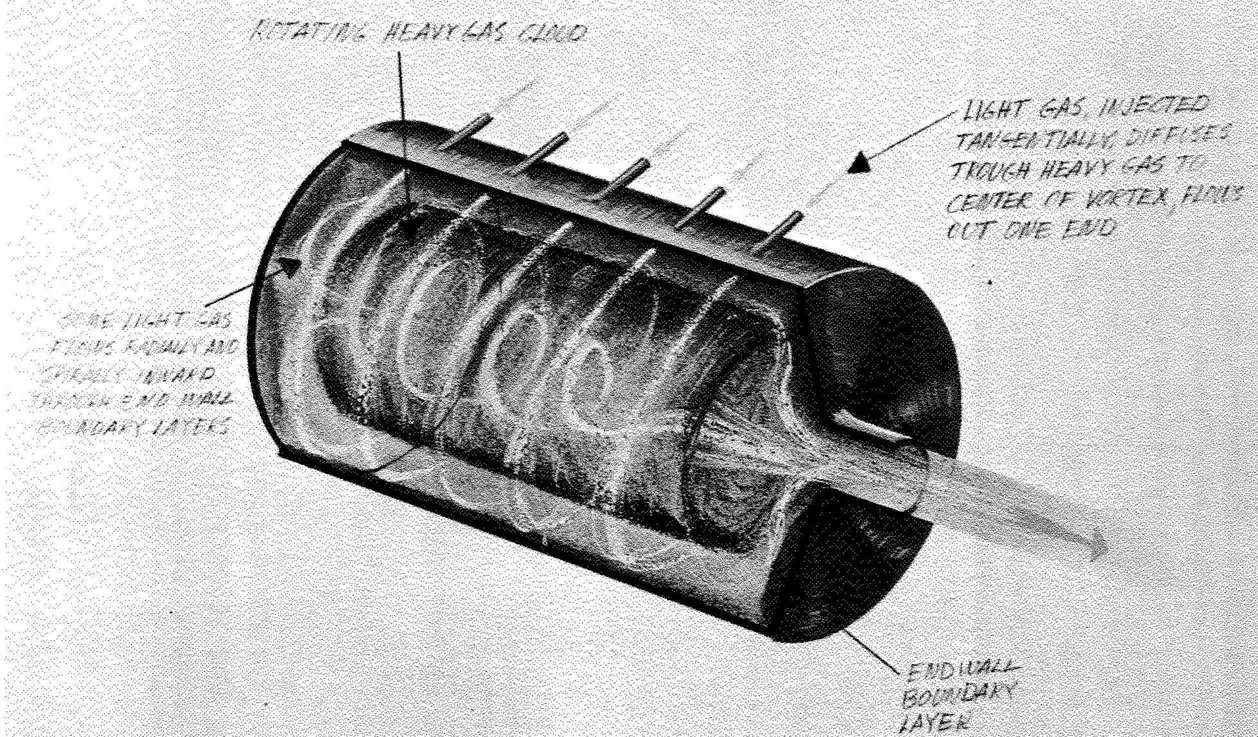


Fig. 5. Dye studies in water vortex (drawings adopted from color photographs) with 0.5 in. exit hole, at static wall-pressure of 2 psig

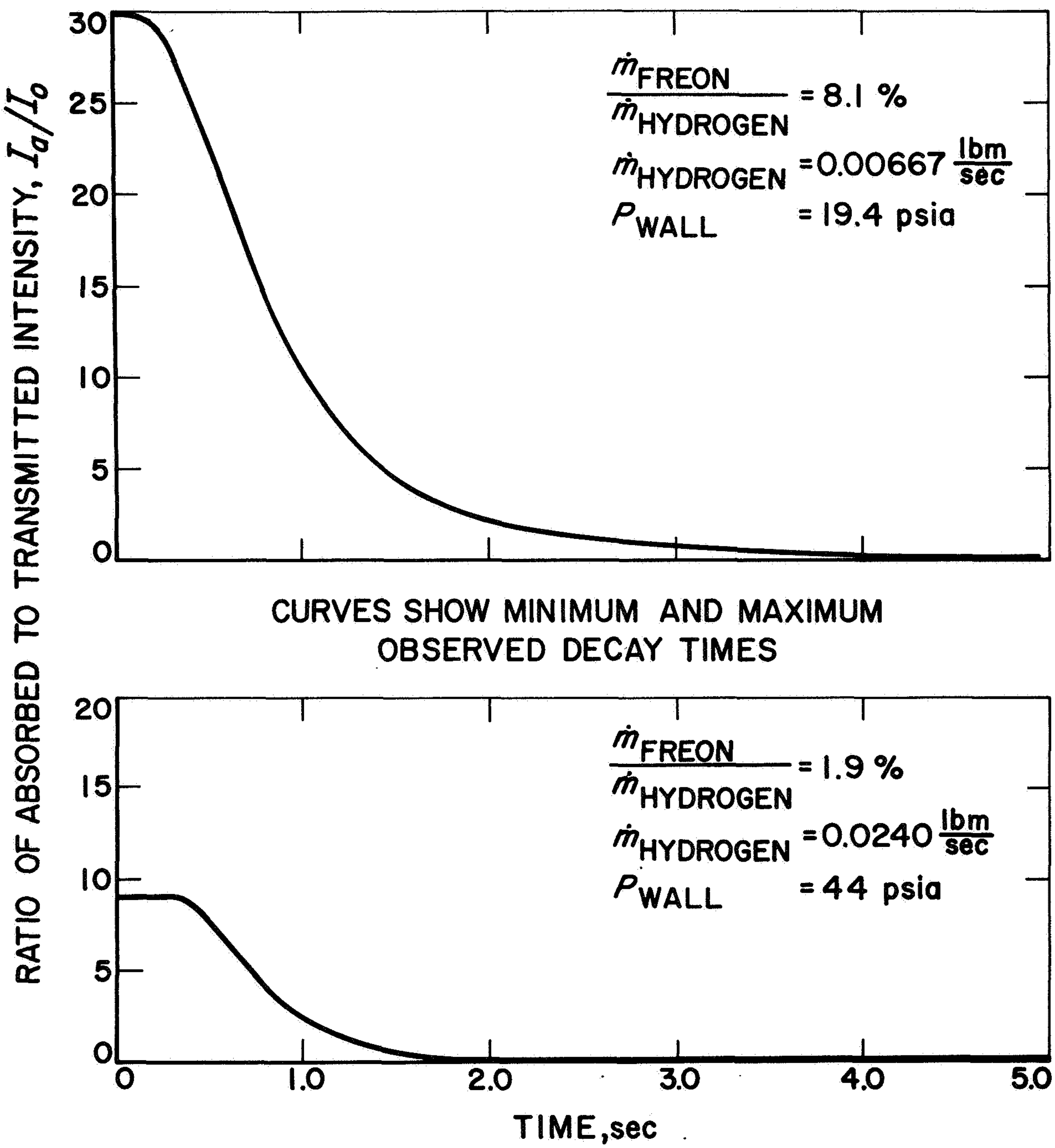
FLUID DYNAMICS STUDY OF BINARY VORTEX FLOWS

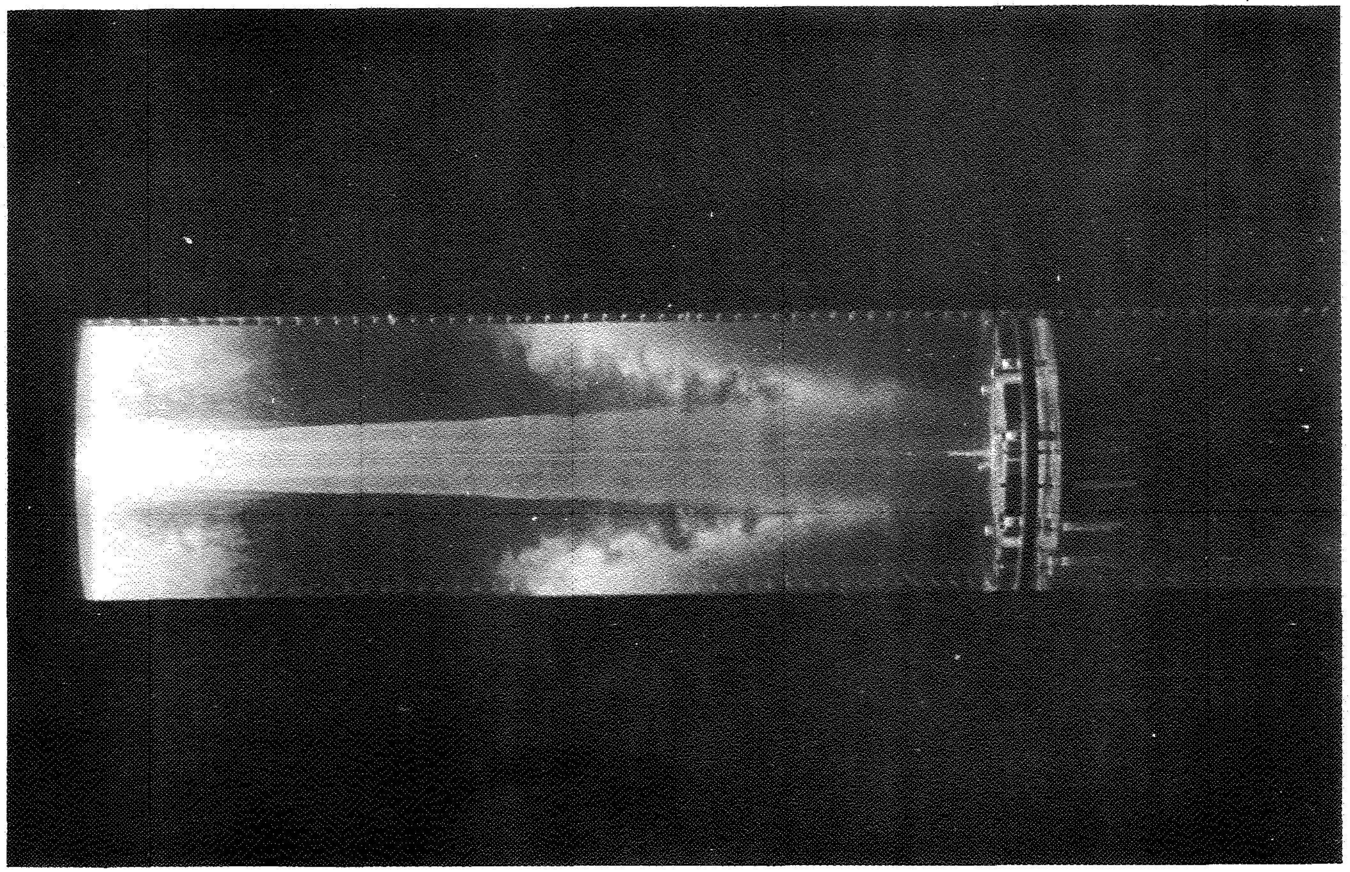


VORTEX FLOWS
OBJECTIVES

TO DETERMINE CONDITIONS THAT WILL PERMIT THE ESTABLISHMENT OF A STABLE VORTEX FLOW CAPABLE OF SUSTAINING AN ORBITING HEAVY GAS THROUGH WHICH A LIGHT GAS CAN DIFFUSE RADIALLY INWARD.

EXPERIMENTAL DECAY OF FREON 13 CONCENTRATION IN THE EXHAUST DUCT OF A HYDROGEN VORTEX AFTER FREON 13 FLOW SHUTOFF





Dye Patterns in
a Water Vortex

JPL Job No. 329-10401-1-3831

RESEARCH AND TECHNOLOGY RESUME	1.	2. GOVT ACCESSION	3. AGENCY ACCESSION NR 000569	
4. DATE OF RESUME 01 04 65	5. KIND OF RESUME D Change	6. SECURITY U (RPT) U (WRK)	7. REGRADING N/A	8. RELEASE LIMITATION NL	9. LEVEL OF RESUME A. Work Unit
10a. CURRENT NUMBER/CODE 129-01-12-01-55			10b. PRIOR NUMBER/CODE		

11. TITLE: Heat Transfer and Fluid Dynamics in Accelerating and Decelerating Flows

12. SCIENTIFIC OR TECH. AREA 006400 Fluid Mech., 014600 Rocket Motors & Engines	13. START DATE 07-60	14. CRIT COMPL DATE N/A	15. FUNDING AGENCY NR OTHER

16. PROCURE. METHOD	17. CONTRACT/GRANT	18. RESOURCES EST	a. PROFESSIONAL MAN YEARS	b. FUNDS (In thousands)
C. In-House	N/A; a. DATE; b. NUMBER; c. TYPE; d. AMOUNT	PRIOR FY 65	0.9	143
		CURRENT FY 66	0.9	140

19. GOVT. LAB/INSTALLATION/ACTIVITY

NAME: Jet Propulsion Laboratory
ADDRESS: 4800 Oak Grove Drive
Pasadena, California 91103

RESP. INDIV.: D. R. Bartz/P. F. Massier
TEL: 213-354- 4060

20. PERFORMING ORGANIZATION N/A

NAME:
ADDRESS:
INVESTIGATORS PRINCIPAL
ASSOCIATE
TEL: TYPE:

21. TECHNOLOGY UTILIZATION

22. COORDINATION

23. KEYWORDS

24. Objective: To contribute to the understanding of convective heat transfer from gases flowing under the influence of accelerating and decelerating pressure gradients. Of particular concern will be the heat transfer and the behavior of the temperature and velocity distributions in the boundary layer along one nozzle, as well as along the constant diameter approach duct attached to the nozzle inlet. The knowledge gained from these investigations will be useful for determining both the local and overall cooling requirements of nozzles, supersonic diffusers, and subsonic-flow constant-

25. diameter ducts in which turbulent-flow convective heat transfer must be evaluated and accounted for in order to maintain the integrity of a device.

Approach: Heat flux distributions to the cooled walls from the hot air stream are determined by calorimetry. Temperature and velocity distributions in the boundary layers are determined from probe measurements along the approach duct and along one of the nozzles. From all of the pressure and temperature measurements that are made, the boundary layer behavior and important parameters such as local mass flux, which influence the convective heat transfer rate, can be deduced. Gas stagnation pressures range between 30 and 250 psia, and stagnation temperatures between 1000 and 2000 $^{\circ}$R.

26. During FY'66, investigation will be continued of the reduction in heat transfer in accelerating flows under certain conditions below that typical of a turbulent boundary layer. It is presently believed that this occurs because of a reduction in turbulence associated with the acceleration.

Progress: The boundary-layer measurements made in the 10° half angle nozzle with cold flow indicate that the effect of the flow acceleration is to alter the velocity distribution from a turbulent 1/7 power profile just upstream of the nozzle inlet to one steeper near the wall and flatter across most of the outer part of the boundary layer inside the nozzle.

27.	28. REQUESTING AGENCY	29. INTER-CENTER SUPPORT	30. CROSS CODE

31. SPECIAL EQUIPMENT

32. FUNDS ($ K)	IN-HOUSE	CONTRACT
PRIOR FY—65	143	N/A
CURRENT FY—66	140	N/A
NEXT FY—		

33. UNIQUE PROJECT	Research Program, SRT
34. SUB PROGRAM	Fluid Physics Research
35. TASK AREA	Combustion, Detonation and Nozzle Flows

NASA FORM 1122 (AUGUST 64)
(Items 1 to 26 identical to DD Form 1498)

(OVER)

CONTINUATION SHEET

Description of FY66 Work Unit Objectives, Approach and Progress

129-01-12-01-55
HEAT TRANSFER AND FLUID DYNAMICS
IN ACCELERATING AND DECELERATING FLOWS
D. R. Bartz, P. F. Massier

Objectives

The general objective of this task is to contribute to the understanding of convective heat transfer from gases flowing under the influence of accelerating and decelerating pressure gradients. During FY66, emphasis will be placed on turbulent free stream flows in two axisymmetric convergent-divergent nozzles which have different configurations and in a supersonic diffuser attached to the exit of one of these nozzles. Of particular concern will be the heat transfer and the behavior of the temperature and velocity distributions in the boundary layer along one nozzle, as well as along the constant diameter approach duct attached to the nozzle inlet. The distributions are of interest because the transport of thermal energy is closely associated with the structure and growth of the boundary layer.

The knowledge gained from these investigations will be useful for determining both the local and overall cooling requirements of nozzles, supersonic diffusers, and subsonic-flow constant-diameter ducts in which turbulent-flow convective heat transfer must be evaluated and accounted for in order to maintain the integrity of a device. Devices to which this type of knowledge may be applied include chemical and nuclear thrust chambers and supersonic exhaust diffusers.

The significant problems that must be solved before adequate knowledge can be gained to understand convective heat transfer in accelerating and decelerating flows are: (1) the behavior of the boundary layer in terms of growth, turbulence level, and temperature and velocity distributions, (2) the local skin friction and its dependence on the flow parameters and (3) in decelerating supersonic flows the interaction phenomena of the complex shock structures with the boundary layer. All of these factors influence the convective heat transfer and the intent is to investigate them to the extent that resource limitations permit.

Approach

Heated compressed air is being directed to flow through the upstream duct, which is used to control the boundary layer thickness, and then through the nozzle and diffuser. Heat flux distributions to the cooled walls from the hot air stream are determined by colarimetry. Temperature and velocity distributions in the boundary layers are determined from probe measurements along the approach duct and along one of the nozzles. Stagnation temperatures and stagnation pressures are determined in the free stream near the nozzle inlet and static pressures are measured along the walls of the entire apparatus. From all of the pressure and temperature measurements that are made the boundary layer behavior and important parameters such as local mass flux, which influence the convective

213

heat transfer rate, can be deduced. If time permits, pressure fluctuations on the walls of the approach duct and hot wire measurements will be made in order to acquire some knowledge of the turbulence level. Gas stagnation pressures range between 30 and 250 psia, and stagnation temperatures between 1000 and 2000°R. Experimental heat transfer results will be compared with analytical predictions and some of the other experimental results such as temperature and velocity distributions in the boundary layer will be used to provide information that must be known or assumed in order to make the analytical heat transfer predictions in nozzles possible. During FY66 investigation will be continued of the reduction in heat transfer in accelerating flows under certain conditions below that typical of a turbulent boundary layer. It is presently believed that this occurs because there may be a reduction in turbulence associated with the acceleration.

Progress

Numerous tests have been conducted on a nozzle that has convergent and divergent half angles of 10°. Velocity distributions as determined from the pressure measurements with a 0.020-in. diameter probe were obtained at a location where the Mach number was about 0.2. Since these preliminary tests were made with compressed air at about room temperature, no temperature distributions were obtained. The boundary-layer measurements made in the 10° half angle nozzle with cold flow indicates that the effect of the flow acceleration is to alter the velocity distribution from a turbulent 1/7 power profile just upstream of the nozzle inlet to one steeper near the wall and flatter across most of the outer part of the boundary layer inside the nozzle. More detail on how this takes place will be determined from traverses at intermediate locations. For the nozzle data obtained thus far, the friction coefficients deduced by matching the velocity distributions in the wall vicinity to the "law of the wall" were found to be about 30% above those predicted by the Blasius relation. A more detailed report of these results is given in the Space Programs Summary listed subsequently.

A technical report, also listed subsequently, has been prepared pertaining to pressure distributions in convergent-divergent nozzles. Experimental results obtained with nozzles having different configurations are compared as are the results with several prediction methods. One of the significant conclusions established by these results is that deviations in static-to-stagnation pressure ratio from plane one-dimensional flow theory amounted to as much as 45% in the throat region. The magnitude of the deviations is governed to a large extent by the ratio of the radius of curvature of the throat to the throat radius. The wall static pressure distribution is related to mass flux distribution which in turn has a primary influence on convective heat flux distribution.

A convergent-divergent nozzle which is designed for a constant pressure gradient is now being fabricated. Tests on this nozzle will be conducted after FY66.

Installation of a pipe line from the hypersonic tunnel high-temperature high pressure dry air supply has been completed. This facility will be used beginning the latter part of FY65. Previous high temperature tests were conducted with the products of combustion of methanol and air and it has been necessary to be cautious to avoid water condensation from taking place along the cold walls of the test apparatus.

REFERENCES

1. L. H. Back, R. Cuffel and H. Gier, "Boundary Layer Velocity Distribution in a 10^{o} Half-Angle Convergent-Divergent Nozzle," SPS 37-31, Vol. IV, JPL, February 28, 1965.

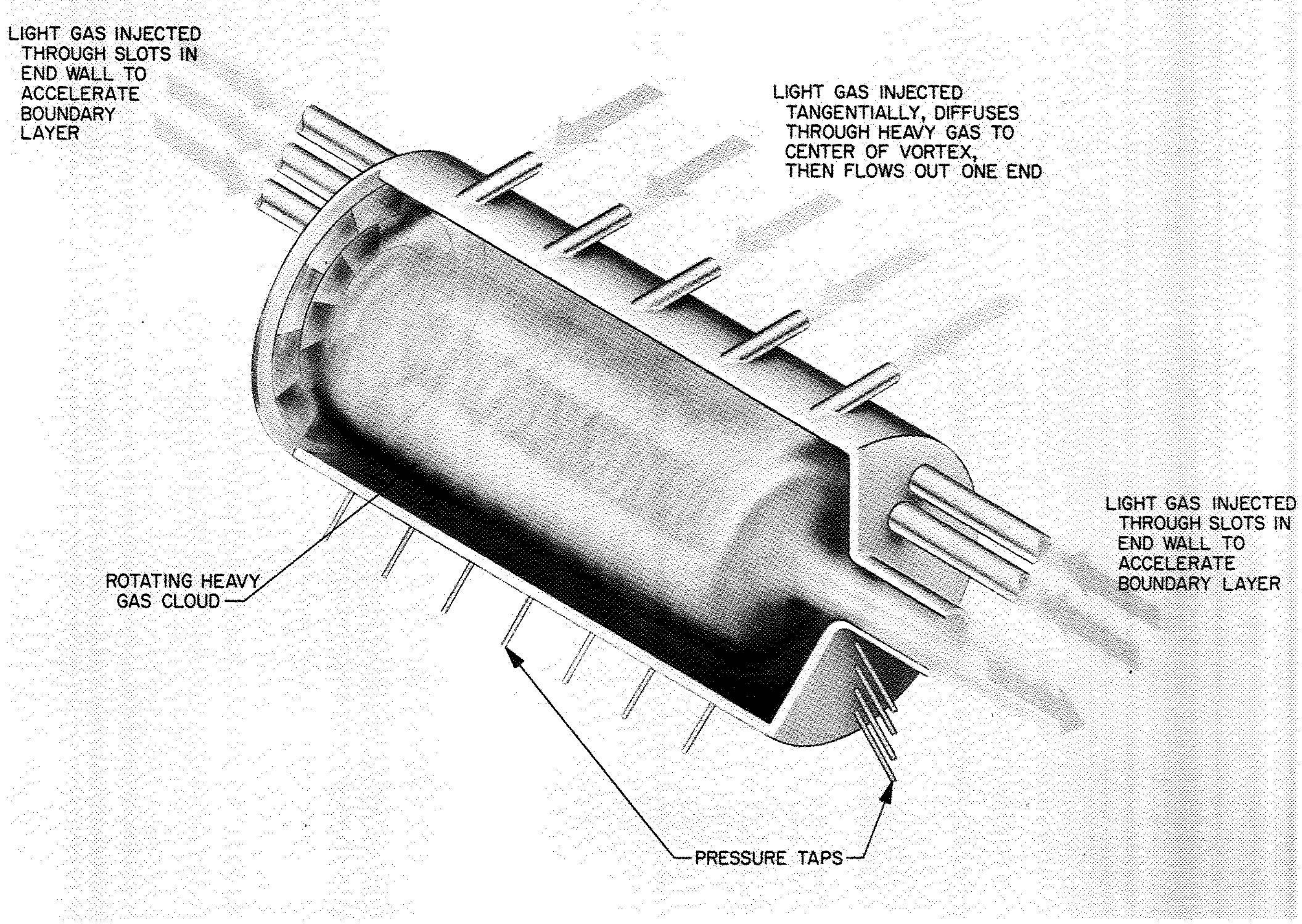
2. L. H. Back, P. F. Massier and H. L. Gier, "Comparisons of Experimental With Predicted Wall Static-Pressure Distributions in Conical Supersonic Nozzles," TR 32-654, JPL, October 15, 1964, also AIAA Journal, Vol. 3, No. 9, September 1965.

3. L. H. Back, P. F. Massier and R. Cuffel, "A More Detailed Investigation of Wall Static Pressure Distributions in a Conical Nozzle With a 45^{o} Half-Angle of Convergence and a 15^{o} Half-Angle of Divergence", Space Programs Summary 37-34, Vol. IV, pp 143-149, August 31, 1965.

4. D. R. Bartz, "Turbulent Boundary-Layer Heat Transfer from Rapidly Accelerating Flow of Rocket Combustion Gases and of Heated Air," Advances in Heat Transfer, Vol. 2, 1965, pp 1-108, Academic Press, New York, New York.

JPL Job No. 329-10401-1-3831
3-9-65

FLUID DYNAMICS INVESTIGATION OF BINARY VORTEX FLOWS



HEAT TRANSFER AND FLUID DYNAMICS IN ACCELERATING AND DECELERATING FLOWS

NASA Work Unit 129-01-12-01
JPL 329-10401-1-3831

A. 45 DEG - 15 DEG NOZZLE

The nozzle that has a convergent half angle of 45 deg, a divergent half angle of 15 deg, and a ratio of the radius of curvature to throat radius $r_c/r_{th} = 0.625$ has been installed in the system. The dams have been repaired so no leakage occurs between the inlet and outlet lines of each passage. Tests with compressed air heated by the combustion of methanol to a stagnation temperature of 1500°R over a pressure range from 30 to 250 psia have been made. A comparison of the new data with the leaking dam data indicates, in particular, significant differences in the nozzle throat region where the variation in the heat flux to the wall is largest. Consequently, only the new data is considered usable. The new data is now being analyzed and some observations are worth noting.

Wall static pressure distributions for the 45 deg - 15 deg nozzle were given in Ref. 1 along with data for other nozzles that have been tested; a slightly condensed version of Ref. 1 has been submitted and accepted for publication in the AIAA Journal. Additional static pressure taps have been installed in the 45 deg - 15 deg nozzle and these reveal two regions where the wall static pressure unexpectedly rises locally other than in the shock-induced flow separation region that is associated with over expanded nozzle operation. These pressure rises occur in the inlet region and just downstream of the tangency between the circular-arc-throat and conical divergent section. In these regions the heat transfer data exhibit trends typical of those found in separated flow regions and, thus, the pressure rise may be enough to cause local flow separation and later flow reattachment. To indicate these observations, wall pressures and heat transfer coefficients are shown in Fig. 1. For the pressure scale chosen, the pressure rise in the inlet is not noticeable; however, the heat transfer behavior is observable because it is also just downstream of the throat. As seen in Fig. 3, there is a reduction in heat transfer at low stagnation pressure below that typical of a turbulent boundary layer. Similar trends were found (in Ref. 2) for the nozzle with a convergent half angle of 30 deg, a divergent half angle of 15 deg and $r_c/r_{th} = 2.0$.

B. CONSTANT PRESSURE GRADIENT NOZZLE

The fabrication of the constant pressure gradient nozzle has reached the stage where the final machining of the inner contour is now being done. The outer skin segments have been welded to the circumferential ribs to form the coolant passages. The pressure tap tubes, coolant passage inlet and outlet tubes, and boundary layer probe inserts have been welded in place. The passages have been checked for leakage across the dams, from passage to passage, and around the boundary layer probe and pressure tap tubes. The nozzle has been stress relieved.

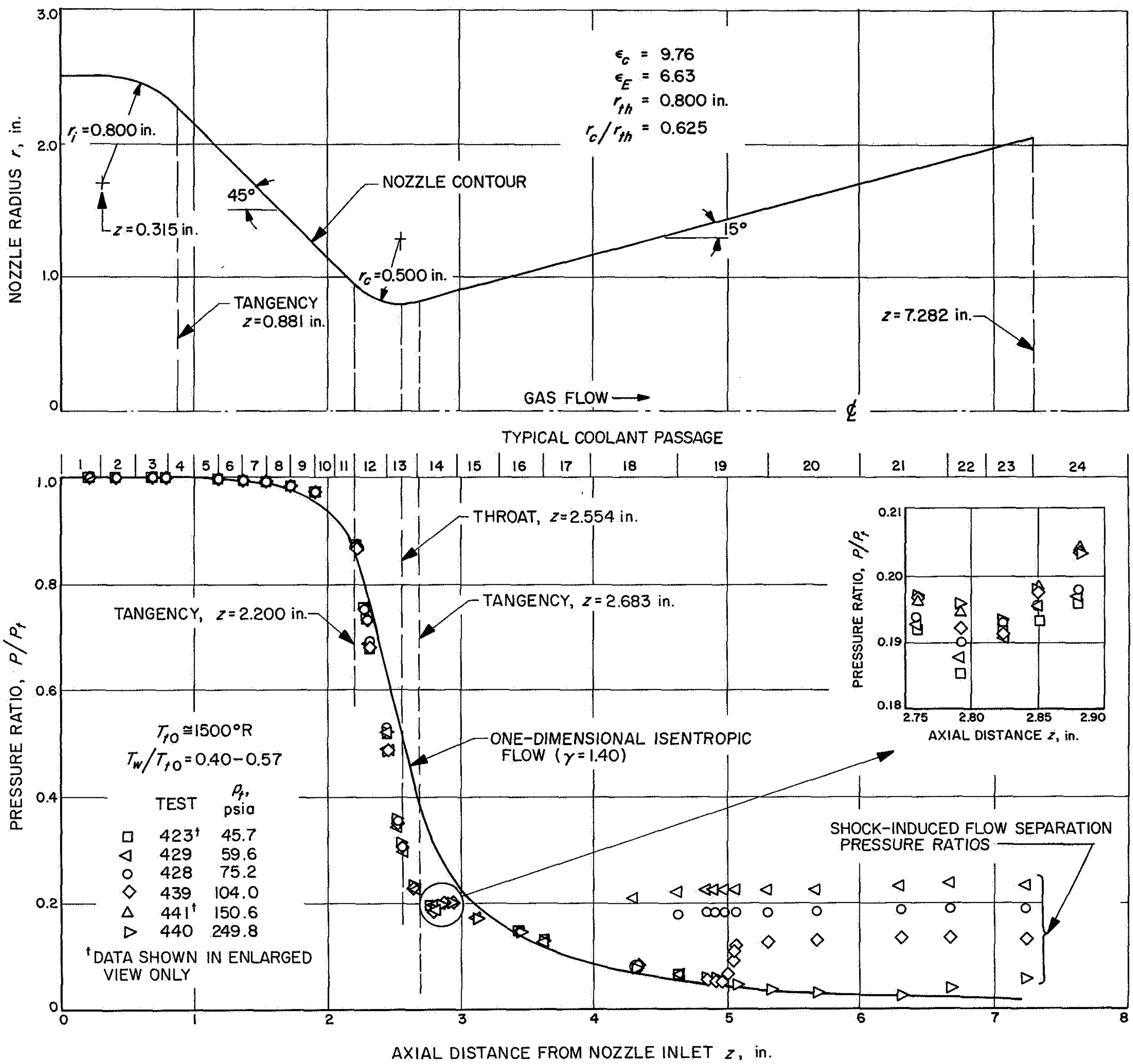


Fig. 1. Static to stagnation pressure ratios along 45 deg - 15 deg nozzle

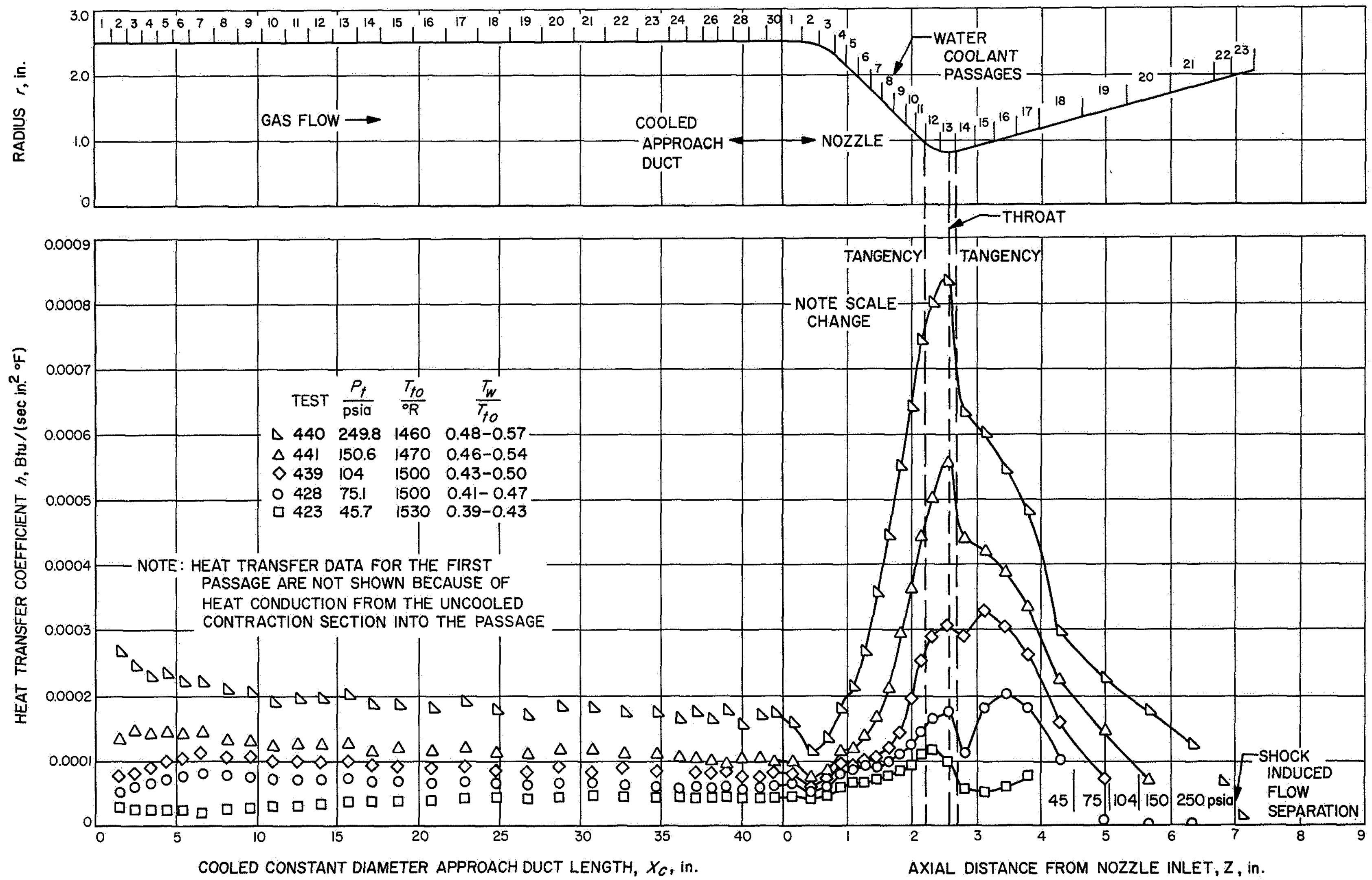


Fig. 2. Variation of heat transfer coefficient along duct and 45 deg - 15 deg nozzle

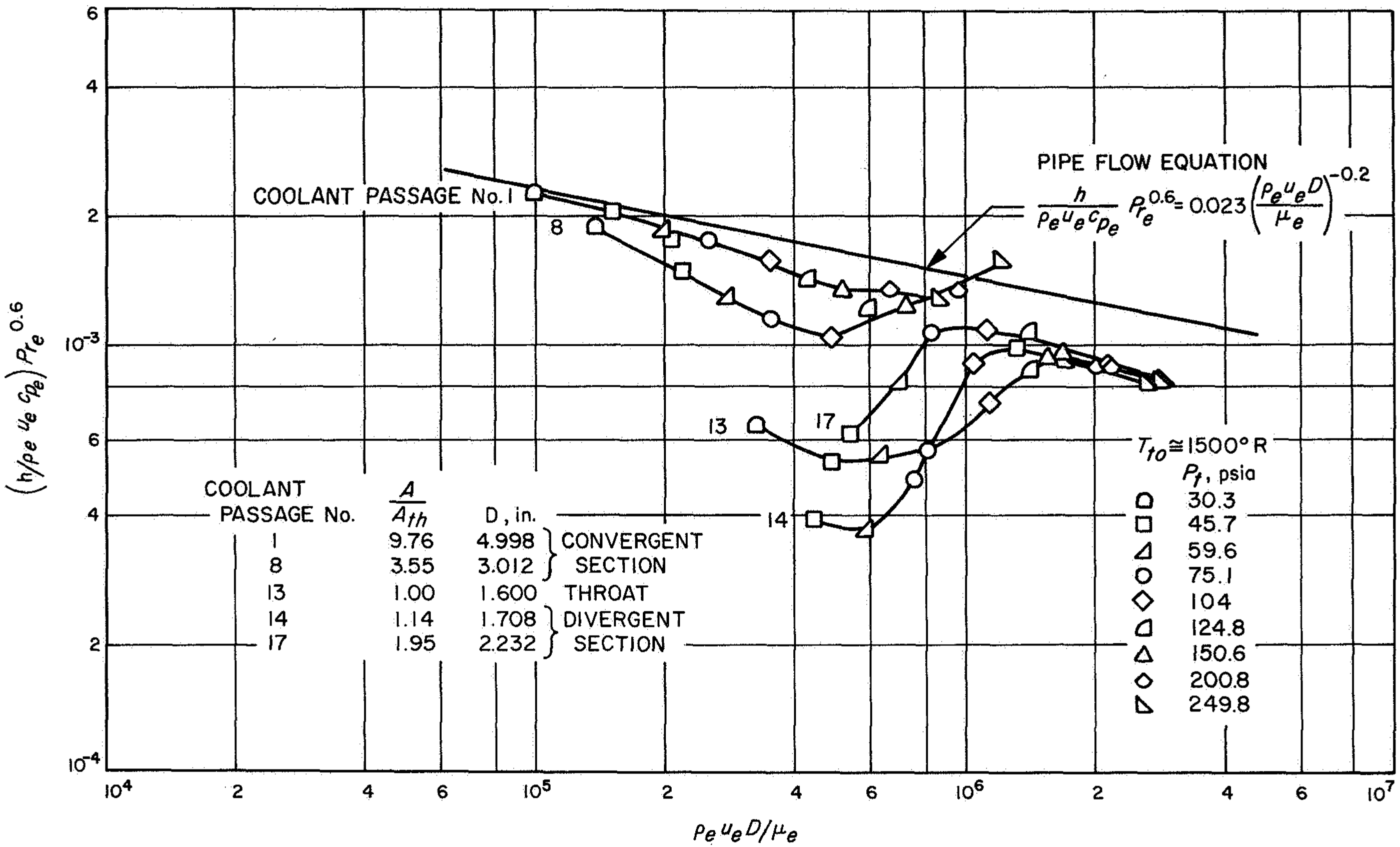


Fig. 3. Variation of Stanton-Prandtl number group at various coolant passages in 45 deg - 15 deg nozzle

C. 10 DEG - 10 DEG NOZZLE

Results of measured velocity distributions in the boundary layer obtained in the 10 deg - 10 deg nozzle are discussed in Ref. 3.

D. TEST FACILITIES AND INSTRUMENTATION

The piping, and controls necessary to use heated air directly from the JPL hypersonic wind tunnel, has now been completed and successfully checked out for test operations in the nozzle heat transfer facility. With this addition the facility has the capability of operation at temperatures up to 700 psia and 1500°R without combustion.

An existing 6-in. long cooled approach section, 5-in. in diameter, has been modified to accommodate four more boundary layer probes. It provides six circumferential probe locations at one axial position to study flow asymmetry upstream of the nozzle inlet. A combination pitot-tube temperature probe has been designed and one has been built. The outside diameter of the probe is 0.042 in. and will allow simultaneous pitot pressure and thermocouple measurements at the same circumferential location.

A pressure scanner that can accommodate 100 channels with 10 transducers is now available for use with this project. It has proven to be satisfactory and reliable and will be installed as soon as transducers now on order are available.

The instrumentation recording capability is being increased to accommodate 250 channels by connecting one additional Dymec recorder that is now used by the Plasma Heat Transfer Project. Connections are being made so that both Dymecs can be used interchangeably by both projects because they share the same test cell.

E. MEETINGS AND DISCUSSIONS

Dr. L. Back attended the NASA Fluid Physics Contractors Conference March 16-19, 1965, and exchanged information with both Dr. R. W. Graham, Head of Experimental Section and Dr. R. G. Deissler, Chief of the Fundamental Heat Transfer Branch, at the Lewis Research Center.

F. PLANNED ACTIVITIES FOR THE FIRST HALF OF FY 1966

Testing of the 45 deg - 15 deg nozzle will continue, with data to be obtained at nominal stagnation temperatures of 1000 and 2000°R and over a stagnation pressure range from 30 to 250 psia. Flow studies will be started to determine if the measured static pressure rise is enough to cause flow separation. Some data will be obtained with the hot air line. These data will be compared to the data that have already been obtained by burning methanol.

The fabrication of the constant pressure gradient nozzle should be completed.

The modified boundary layer probe section with six probe locations will be installed upstream of the nozzle to study flow asymmetries.

The 10 deg - 10 deg nozzle will be repaired, a few static pressure taps added, and the nozzle will be installed after the 45 deg - 15 deg nozzle tests are completed.

G. REFERENCES

1. Back, L. H., Massier, P. F. and Gier, H. L., Comparisons of Experimental with Predicted Wall Static Pressure Distributions in Conical Supersonic Nozzles, Technical Report No. 32-654, Jet Propulsion Laboratory, Pasadena, October 15, 1964; also to be published in AIAA Journal.

2. Back, L. H., Massier, P. F. and Gier, H. L., Convective Heat Transfer in a Convergent-Divergent Nozzle (Revision No. 1), Technical Report No. 32-415, Jet Propulsion Laboratory, Pasadena, Feb. 15, 1965 - also in International Journal of Heat Mass Transfer, Vol. 7, No. 5, pp. 549-568 (1964).

3. Back, L. H., Cuffel, R. and Gier, H., Boundary Layer Velocity Distributions in a 10° Half Angle Convergent-Divergent Nozzle, Jet Propulsion Laboratory Space Programs Summary No. 37-31, Vol. IV, pp. 169-174, Feb. 28, 1965.

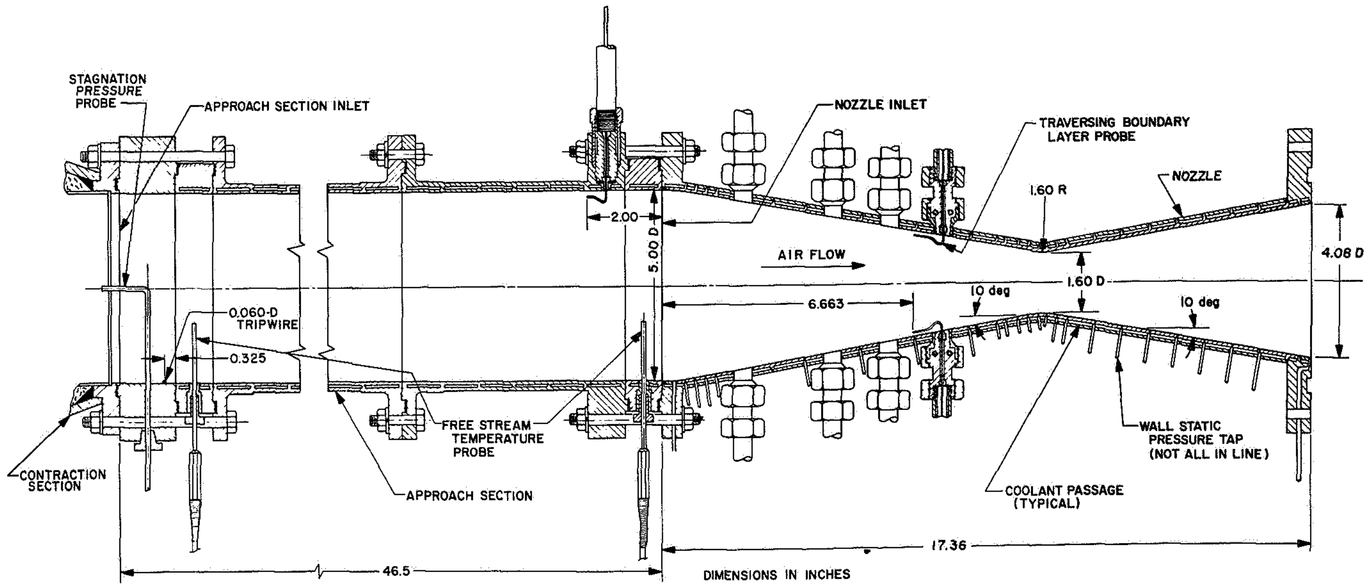
CONVECTIVE HEAT TRANSFER
OBJECTIVES

1. TO GAIN AN UNDERSTANDING OF CONVECTIVE HEAT TRANSFER AND FLUID DYNAMIC PHENOMENA OF ACCELERATING AND DECELERATING FLUID FLOWS.
2. TO CORRELATE EXPERIMENTAL RESULTS.
3. TO DEVELOP AN IMPROVED METHOD FOR PREDICTING LOCAL HEAT TRANSFER RATES FROM FLUIDS FLOWING UNDER THESE CONDITIONS.

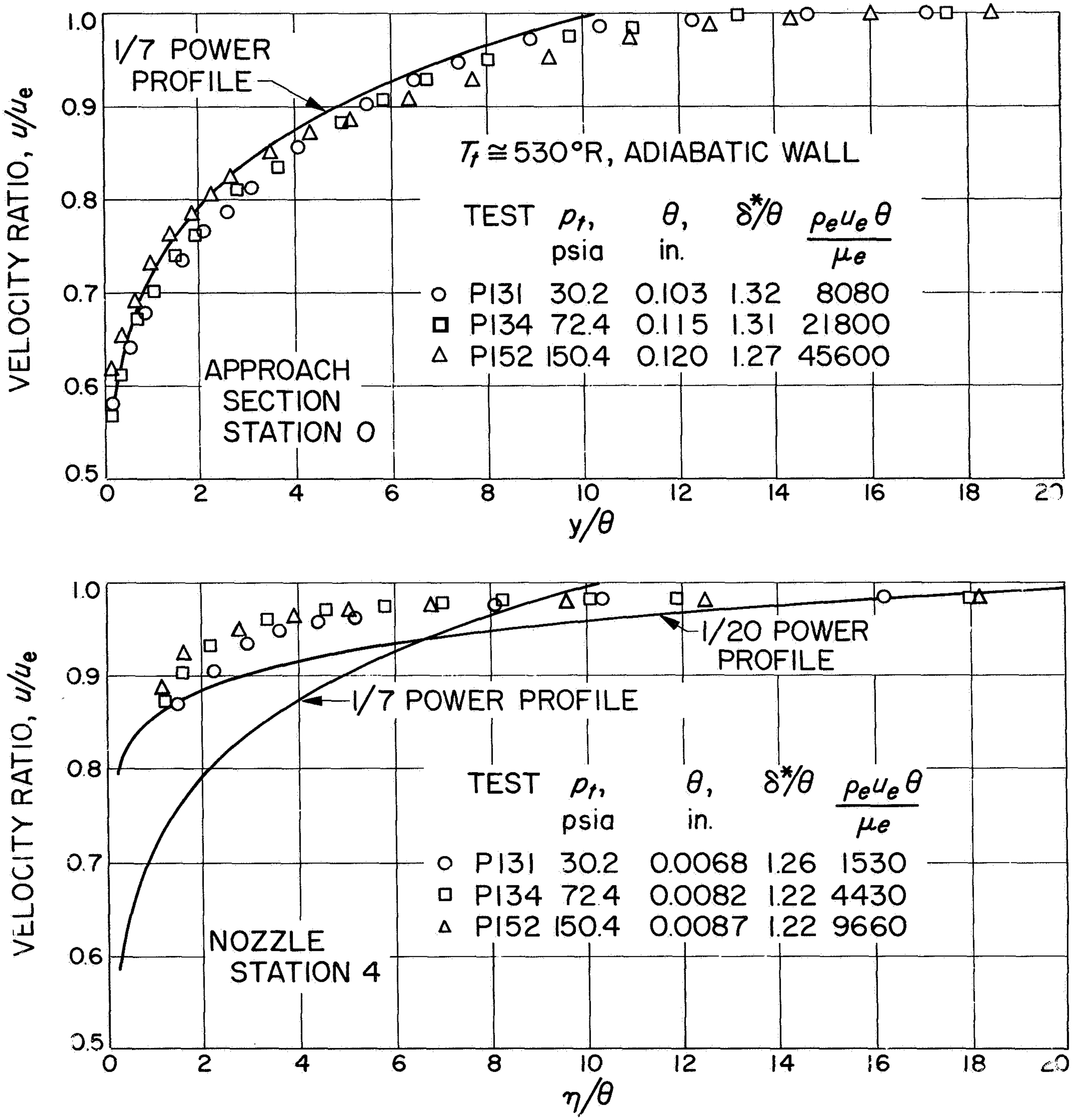
CONVECTIVE HEAT TRANSFER

PRESENT INVESTIGATION INCLUDES:

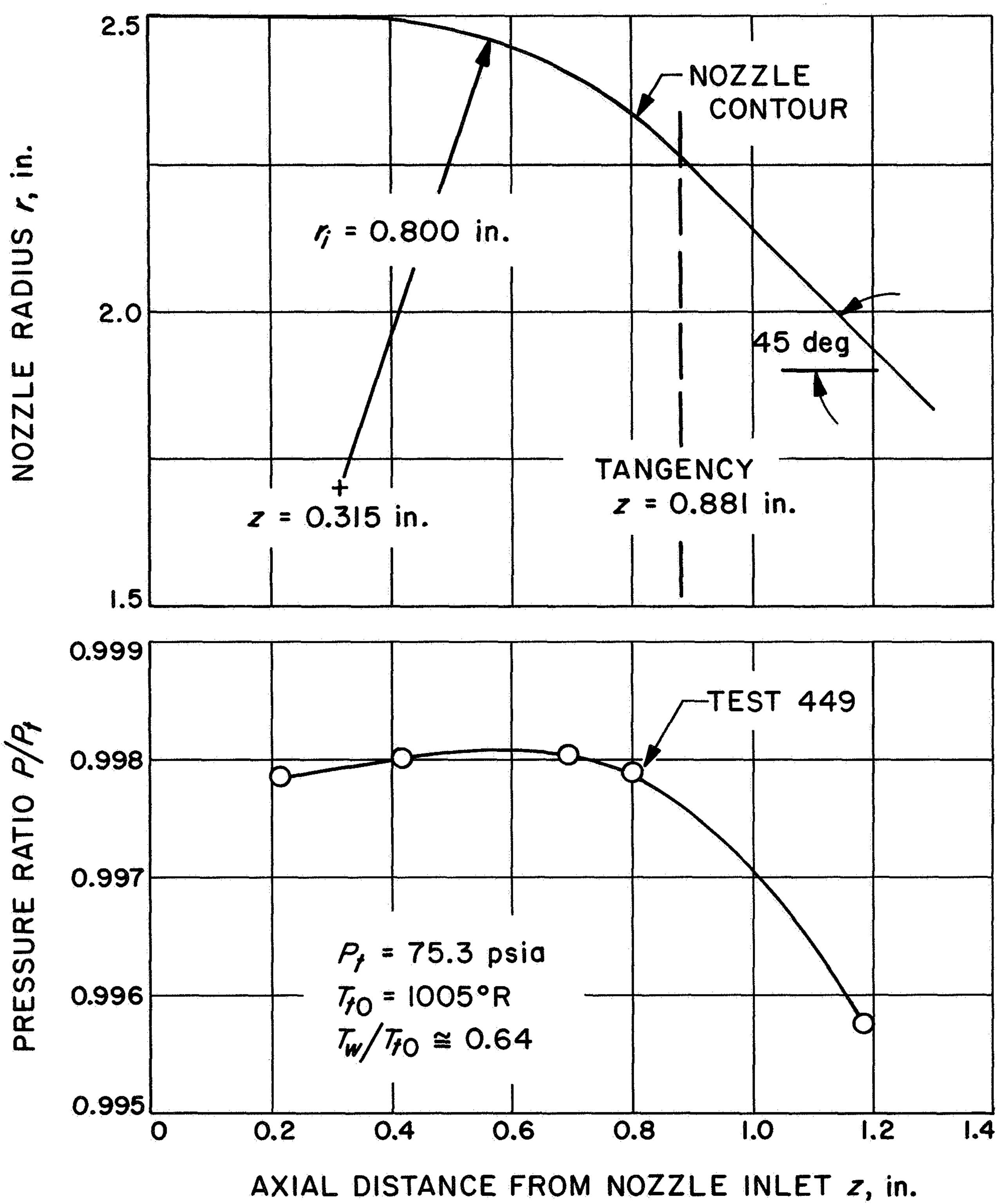
7. USE OF THE PRODUCTS OF COMBUSTION OF METHANOL AND AIR AS WELL AS AIR HEATED BY FLOW OVER AN ELECTRIC HEATER.
8. MEASUREMENT OF WALL HEAT FLUX AND STATIC PRESSURE.
9. MEASUREMENT OF BOUNDARY-LAYER STAGNATION PRESSURE AND TEMPERATURE DISTRIBUTIONS IN NOZZLES AND CONSTANT-DIAMETER INLET DUCTS.
10. FREE-STREAM STAGNATION PRESSURE AND TEMPERATURE MEASUREMENTS



APPROACH SECTION AND 10°-10° NOZZLE TEST APPARATUS.

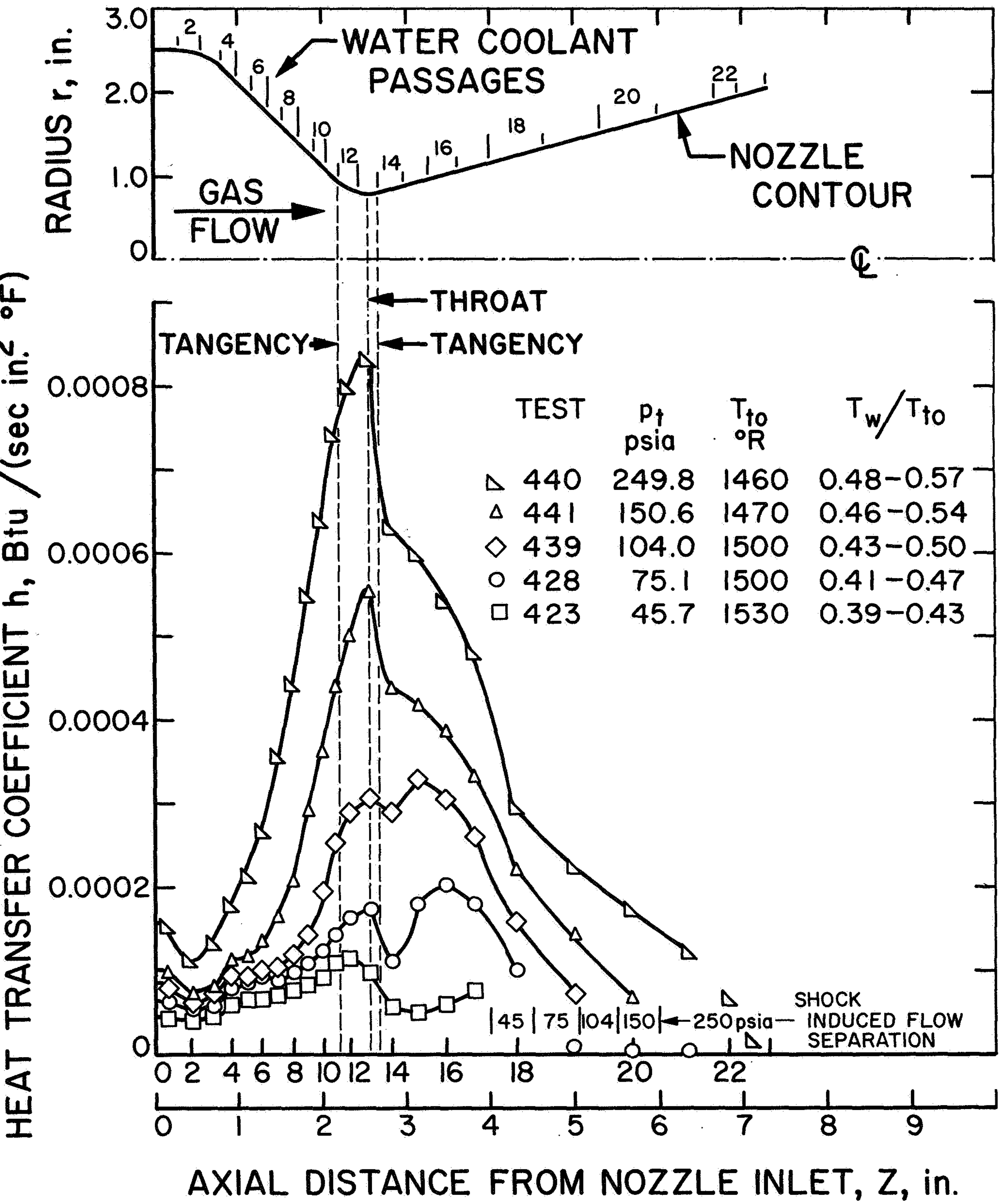


BOUNDARY-LAYER VELOCITY DISTRIBUTIONS IN THE APPROACH SECTION AND 10°-10° NOZZLE.

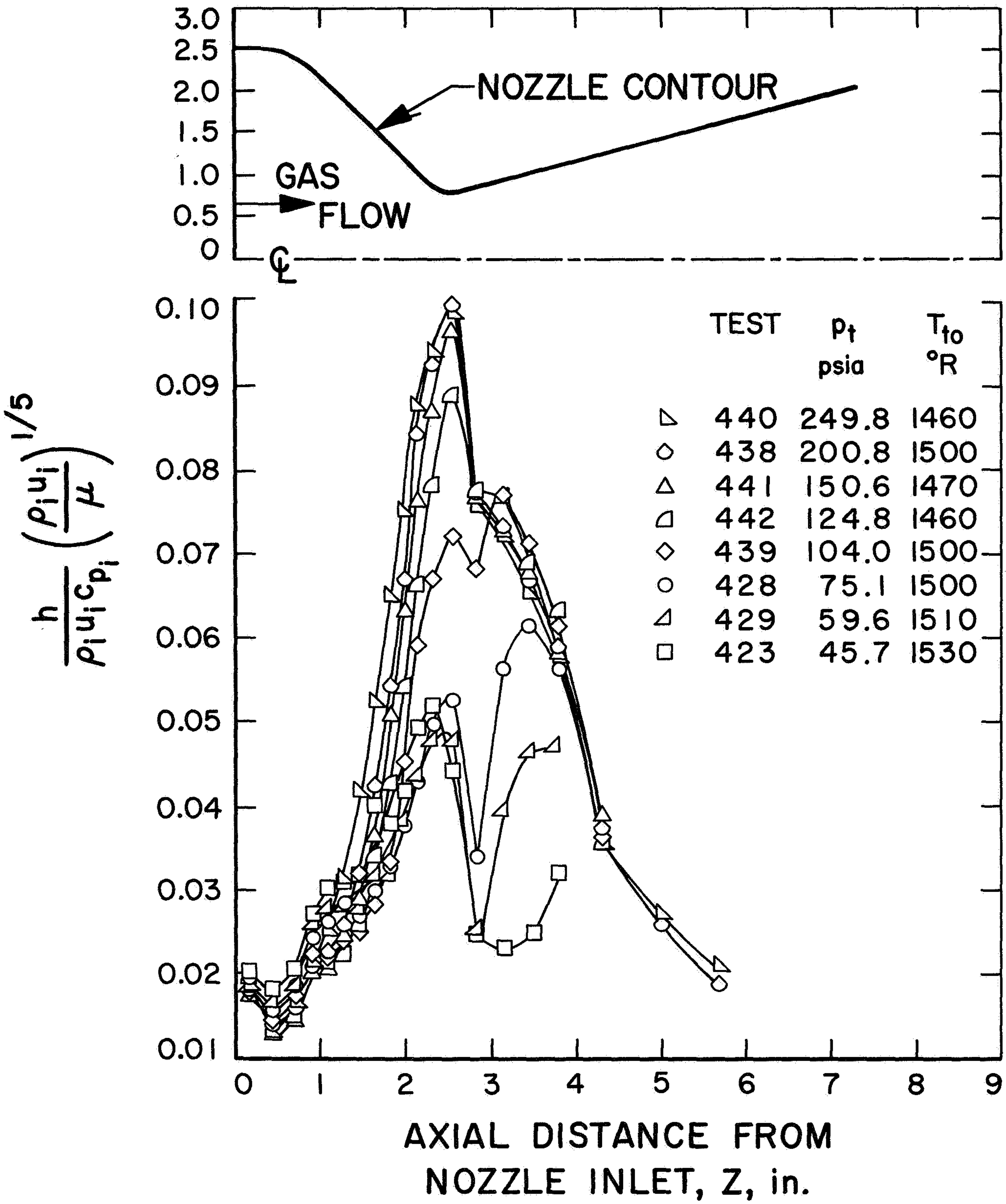


NOZZLE RADIUS r, in.
2.5
2.0
1.5
NOZZLE CONTOUR
r_i = 0.800 in.
45 deg
TANGENCY
z = 0.881 in.
z = 0.315 in.
PRESSURE RATIO P/P_t
0.999
0.998
0.997
0.996
0.995
TEST 449
P_t = 75.3 psia
T_{t0} = 1005°R
$T_w/T_{t0} \cong 0.64$
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
AXIAL DISTANCE FROM NOZZLE INLET z, in.

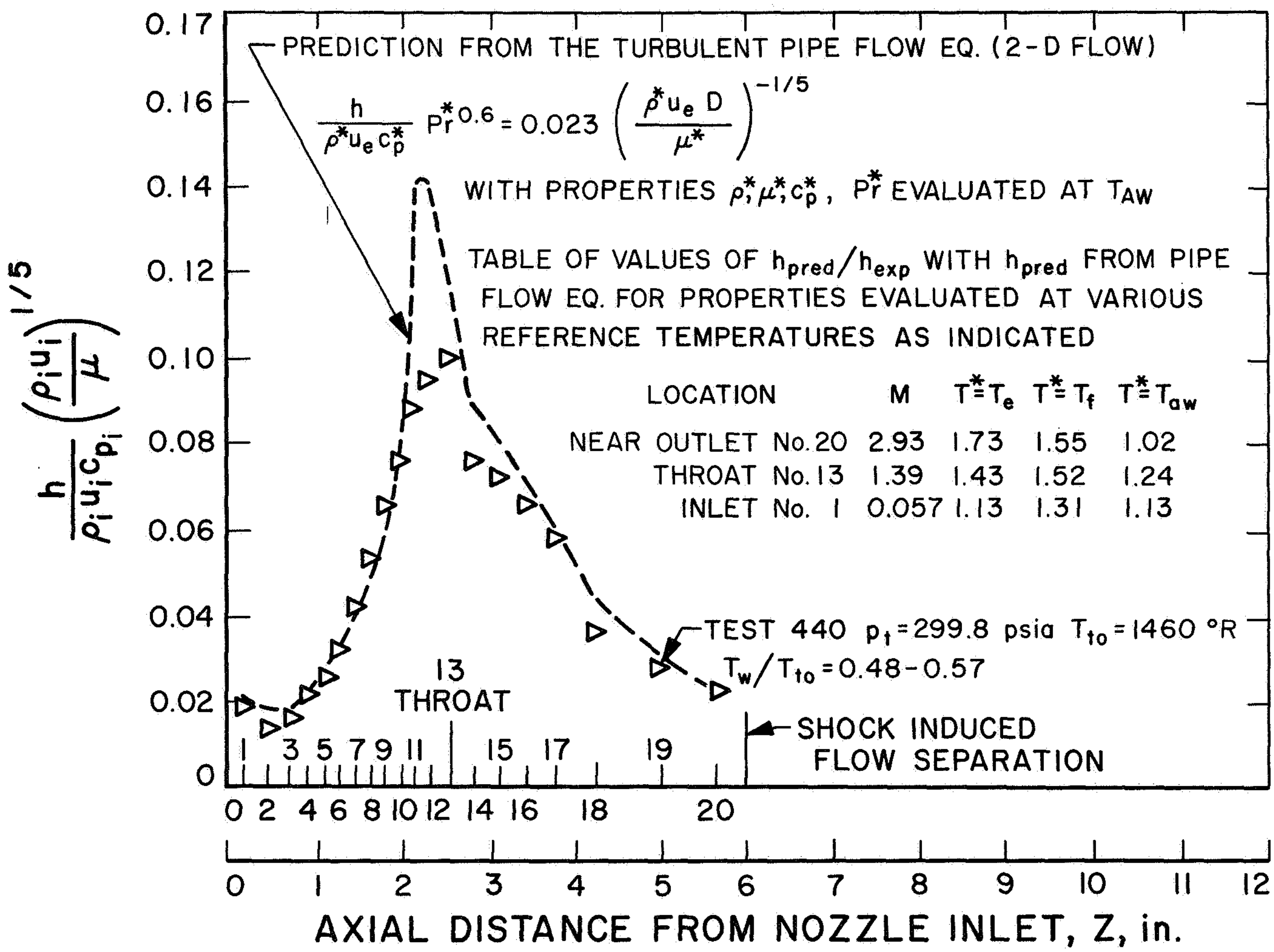
HEAT TRANSFER COFFICIENTS ALONG THE 45°-15° NOZZLE



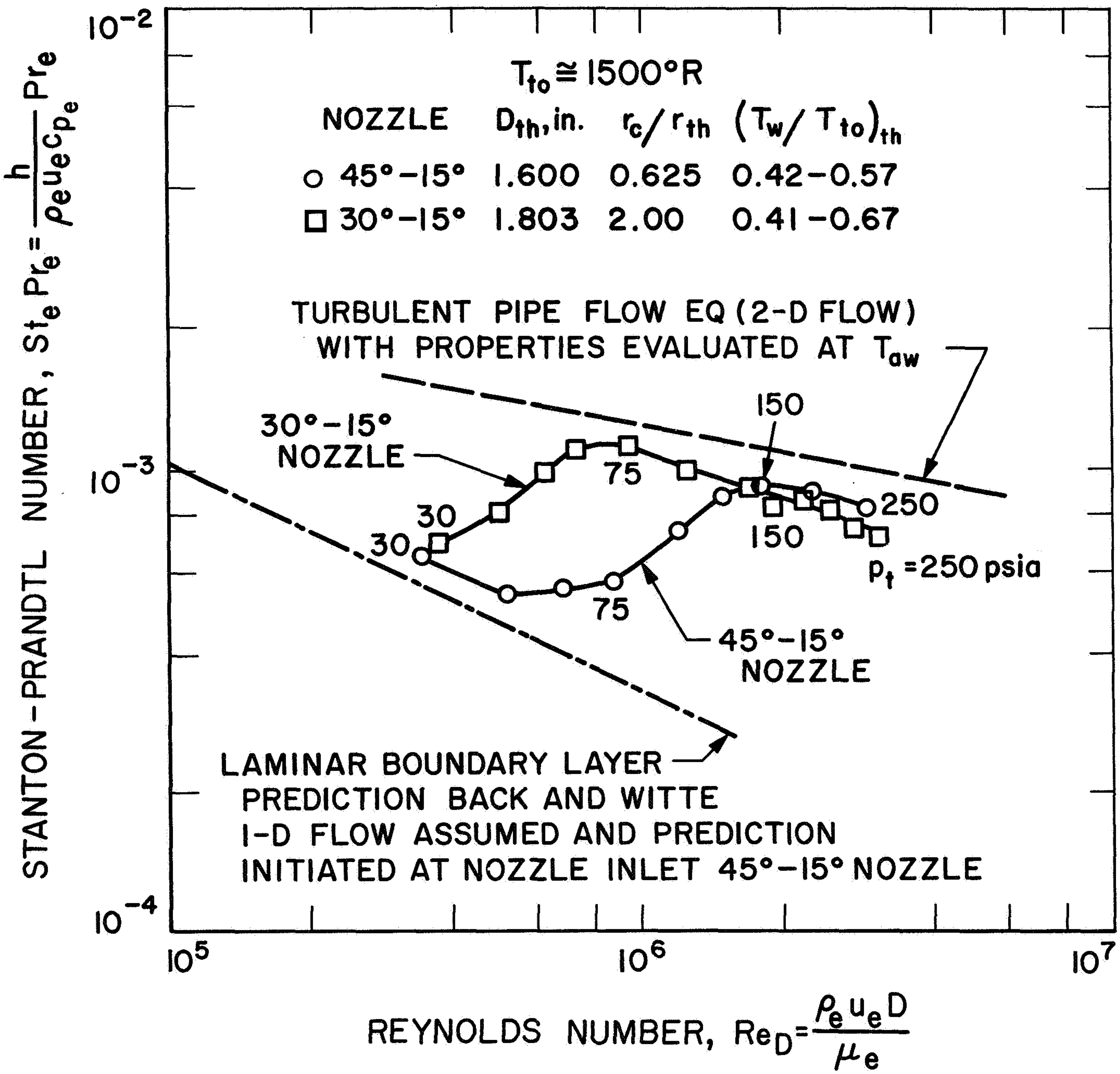
VARIATION OF THE STANTON-REYNOLDS NUMBER GROUP ALONG THE 45°-15° NOZZLE



TURBULENT HEAT TRANSFER PREDICTIONS FOR THE 40°-15° NOZZLE AT THE HIGH STAGNATION PRESSURE



VARIATION OF THE STANTON-PRANDTL NUMBER GROUP AT THE NOZZLE THROAT

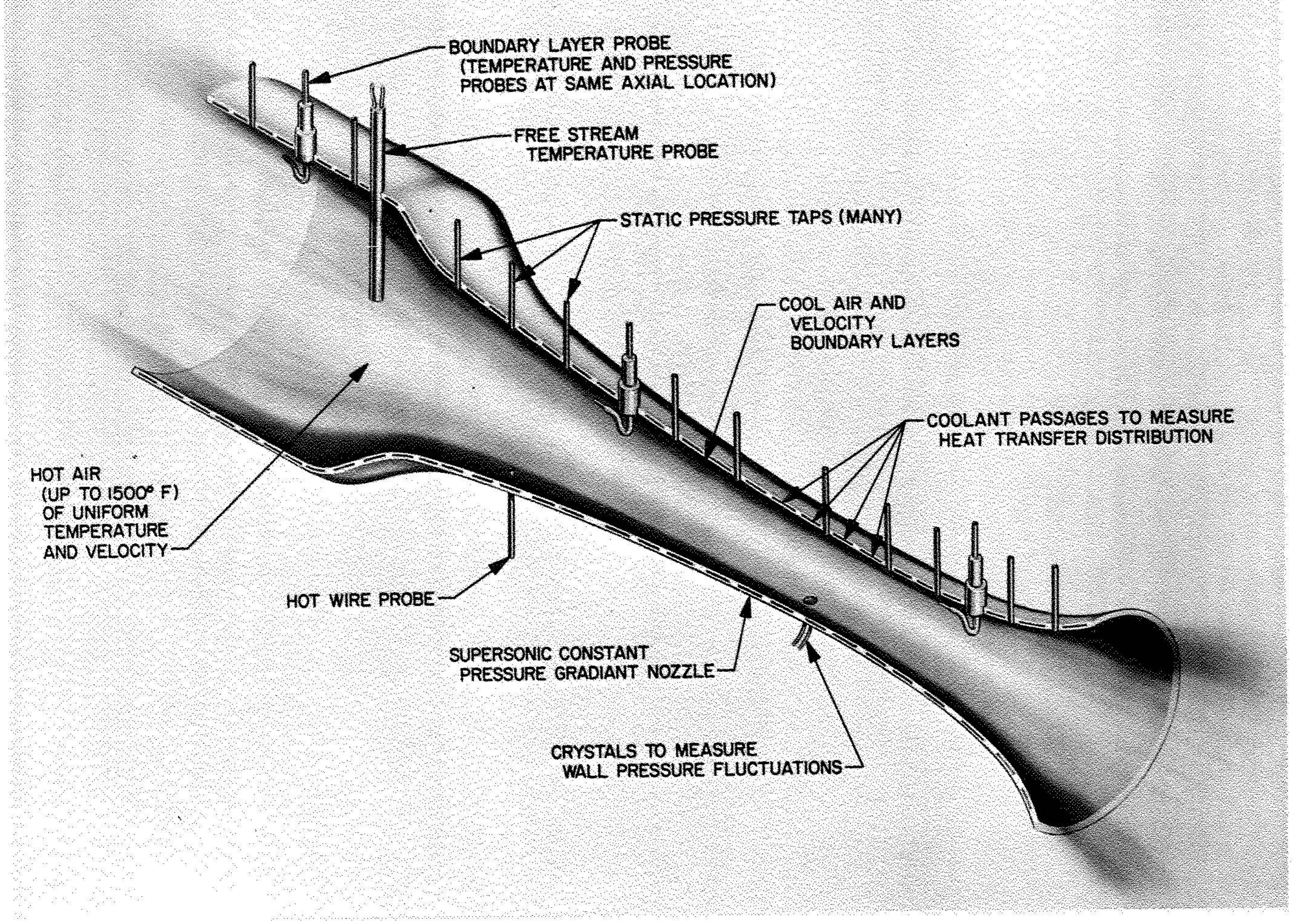


CONVECTIVE HEAT TRANSFER

ANTICIPATED FUTURE EXPERIMENTAL INVESTIGATIONS:

1. STAGNATION TEMPERATURES UP TO 3500 DEG. F.
2. STAGNATION PRESSURES UP TO 500 PSIA.
3. HEAT TRANSFER AND WALL STATIC PRESSURE MEASUREMENTS IN A SUPERSONIC DIFFUSER.
4. TURBULENCE INTENSITY MEASUREMENTS IN THE FREE STREAM AND BOUNDARY LAYERS WITH A HOT WIRE.
5. MEASUREMENT OF PRESSURE FLUCTUATIONS ON THE WALL OF A NOZZLE.
6. BOUNDARY LAYER AND FREE STREAM PRESSURE, TEMPERATURE, AND TURBULENCE INTENSITY MEASUREMENTS IN THE TRANSONIC REGION OF A CONSTANT-PRESSURE-GRADIENT NOZZLE.

CONVECTIVE HEAT TRANSFER IN NOZZLES



JPL Job No. 329-10701-1-3831

RESEARCH AND TECHNOLOGY RESUME

1.	2. GOVT. ACCESSION	3. AGENCY ACCESSION: NR 000566	
4. DATE OF RESUME: 01 04 65	5. KIND OF RESUME: D Change	6. SECURITY: U RPT, U WRK	7. REGRADING: N/A
8. RELEASE LIMITATION: NL	9. LEVEL OF RESUME: A. Work Unit		

10a. CURRENT NUMBER/CODE: 129-01-09-04-55

10b. PRIOR NUMBER/CODE:

11. TITLE: Plasma Heat Transfer

12. SCIENTIFIC OR TECH. AREA: 006400 Fluid Mechanics, 013000 Plasma Physics, 005400 Elect. Prop.

13. START DATE: 07-60

14. CRIT. COMPL. DATE: N/A

15. FUNDING AGENCY: NR OTHER

16. PROCURE. METHOD: C. In-House

17. CONTRACT/GRANT: N/A
a. DATE
b. NUMBER
c. TYPE
d. AMOUNT

18. RESOURCES EST.	a. PROFESSIONAL MAN-YEARS	b. FUNDS (In thousands)
PRIOR FY-65	1.7	226
CURRENT FY-66	3.5	335

19. GOVT. LAB/INSTALLATION/ACTIVITY

NAME: Jet Propulsion Laboratory
ADDRESS: 4800 Oak Grove Drive
Pasadena, California 91103

RESP. INDIV.: D. R. Bartz/P. F. Massier
TEL: 213-354-4060

20. PERFORMING ORGANIZATION

NAME: N/A
ADDRESS:
INVESTIGATORS
PRINCIPAL:
ASSOCIATE:
TEL: TYPE:

21. TECHNOLOGY UTILIZATION

22. COORDINATION

23. KEYWORDS

24. Objectives: to contribute to the understanding of convective and radiative heat transfer associated with ionized gases flowing under the influence of applied pressure gradients, magnetic fields, and electric fields. Progressive refinements in the evaluation of total radiation from arcs and from mixed thermally ionized gases as well as convection from ionized gases will be made available for the design of devices in which these modes of heat transfer occur. Realistic predictions based on experiments will also be possible for devices in which the heat transfer may be influenced by the

25. presence of applied electric and magnetic fields such as crossed-field accelerators and decelerators for propulsion and power and thermal arc jet facilities.
Approach: Wall static pressure measurements and total heat flux measurements by calorimetry are being made from ionized gases flowing through constant diameter ducts, convergent-divergent nozzles and supersonic diffusers. Gases are ionized by an electric arc and hence, heat flux distributions along arc head anodes are also being investigated. The radiation component from the arc has been isolated from the rest of the apparatus by locating the arc so that most of it cannot be viewed by components other than electrodes. Total radiation from the gas upstream of the nozzle is being

26. measured by use of a hohlraum.
Progress: Preliminary tests have indicated that swirl does have a significant heat transfer effect in the convergent part of a nozzle which is located downstream of an arc head but not so much in the divergent part. Preparation of a technical report which pertains to one-dimensional isentropic flow of partially ionized argon has been completed. A report has also been prepared and submitted for external publication on the prediction of heat transfer from laminar boundary layers with emphasis on large free stream velocity gradients and highly cooled walls.

27.	28. REQUESTING AGENCY	29. INTER-CENTER SUPPORT	30. CROSS CODE

31. SPECIAL EQUIPMENT

32. FUNDS ($ K)	IN-HOUSE	CONTRACT
PRIOR FY-65	226	N/A
CURRENT FY-66	335	N/A
NEXT FY-		

33. UNIQUE PROJECT: Research Program, SRT

34. SUB PROGRAM: Fluid Physics Research

35. TASK AREA: Heat, Mass and Momentum Transfer.

NASA FORM 1122 (AUGUST 64)
(Items 1 to 26 identical to DD Form 1498)

(OVER)

CONTINUATION SHEET

Description of FY66 Work Unit Objectives, Approach and Progress

129-01-09-04-55
PLASMA HEAT TRANSFER
D. R. Bartz, P. F. Massier

Objectives

The general objectives of this task are to contribute to the understanding of convective and radiative heat transfer associated with ionized gases flowing under the influence of applied pressure gradients, magnetic fields, and electric fields. Progressive refinements in the evaluation of total radiation from arcs and from mixed thermally ionized gases as well as convection from ionized gases will be made available for the design of devices in which these modes of heat transfer occur. Realistic predictions based on experiments will also be possible for devices in which the heat transfer may be influenced by the presenc of applied electric and magnetic fields such as cross-field accelerators and decelerators for propulsion and power, and thermal arc jet facilities.

Approach

Wall static pressure measurements and total heat flux measurements by calorimetry are being made from ionized argon flowing through constant diameter ducts, convergent-divergent nozzles and supersonic diffusers. Gases are ionized by an electric arc and hence, heat flux distributions along arc-head anodes are also being investigated. The radiation component from the arc has been isolated from the rest of the apparatus by locating the arc so that most of it cannot be viewed by components other than the electrodes. Total radiation from the gas upstream of the nozzle is being measured by use of a hohlraum. Measurement of the radiation will also be attempted by use of a probe. The convection component is then deduced by subtracting the radiation component from the total heat flux. During FY66 radial stagnation enthalpy and pressure distributions will be continued by use of a cooled traversing probe. Spectroscopic measurements will be made to determine gas temperature. During FY66 experiments will be initiated on ionized argon flow through rectangular channels located downstream of a nozzle. Magnetic and electric fields will be applied across these channels an an attempt will be made to measure the force on the magnet which is associated with the acceleration or deceleration of the flow.

Several analyses are being programmed on a digital computer. These will be used to make comparisons of the flow variables using the various prediction methods. Some of the measurements such as static pressure and heat flux distributions will be used as boundary conditions to predict other flow variables. These analyses differ by the assumptions that are made, some of which are: (1) one-dimensional isentropic core flow, (2) quasi two-dimensional flow with heat transfer, (3) non-equilibrium flow, which incorporates the use of recombination rate equations.

Since swirl is frequently employed to help stabilize an arc, the influence of the swirl component on the flow field and on heat transfer is being investigated and this will be continued during FY66. Both room temperature and high temperature gases are being used.

205

Progress

Preliminary tests have indicated that swirl does have a significant heat transfer effect in the convergent part of a nozzle which is located downstream of an arc head but not so much in the divergent part. Cold flow tests indicate that the tangential velocity component is high at the nozzle inlet for a comparatively high injection velocity in comparison to the axial component but becomes less important as the flow accelerates through the nozzle since the axial component accelerates much more rapidly than the tangential component.

Preparation of a technical report which pertains to one-dimensional isentropic flow of partially ionized argon has been completed. Results are presented in tabular, as well as graphical form, so that trends as well as accurate numerical values may be easily determined. Equilibrium thermodynamic equations derived by the partition function method were combined with the one-dimensional flow equations and solved numerically on a digital computer to obtain the results. A report has also been prepared and submitted for external publication on the prediction of heat transfer from laminar boundary layers with emphasis on large free stream velocity gradients and highly cooled walls. Ionization was neglected; however, the approach is believed to be valid for gases that have small ionization to total energy fractions.

Experimental results on thermally ionized argon that have been obtained thus far include total heat flux distributions to the walls of an axisymmetric test apparatus consisting of arc head electrodes, mixing chamber, supersonic nozzle and a supersonic diffuser. No external magnetic or electric fields have as yet been applied except across the upstream electrodes in order to ionize the argon. Static pressure distributions have been made along the mixing chamber, nozzle and diffuser and some radiant energy measurements have been made in the mixing chamber with a cooled hohlraum. The knowledge acquired from these tests has been reported in the Space Programs Summaries listed in the References. At the nozzle inlet, average stagnation temperatures based on an energy balance have ranged up to about 12,000°K, ionization fractions up to 0.26, stagnation enthalpies up to 7600 Btu/lb and stagnation pressures between 0.1 and 2.0 atmospheres.

Significant results of these tests are: (1) the maximum heat flux occurs to the anode which is attributed largely to the electron bombardment, (2) under certain conditions, the heat fluxes to the nozzle walls have been large enough that about 70% of the total energy at the inlet was transferred to the nozzle by the time the flow reached the throat, (3) if it is assumed that the total heat transferred to the nozzles is caused primarily by convection, the trends in terms of Stanton number vs. Reynolds number are similar to those obtained for unionized argon except for an apparent additional influence of the stagnation pressure, (4) the slopes of the trends are somewhat different for the two different nozzles, (5) swirl in the flow tends to shift the peak heat flux location of the nozzle farther upstream of the throat than when no swirl is present.

Insufficient data have as yet been obtained to make conclusive statements regarding the comparative magnitude of the thermal radiation.

'06

REFERENCES

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3. P. F. Massier and M. B. Noel, "Heat Transfer From Ionized Gases," Space Programs Summary 37-19, Vol. IV, pp 119-125, JPL, February 28, 1963.

4. P. F. Massier, M. B. Noel and L. H. Back, "Heat Transfer From Ionized Gases," Space Programs Summary 37-22, Vol. IV, pp 119-125, JPL, August 31, 1963.

5. P. F. Massier, L. H. Back, A. B. Witte and M. B. Noel, "Heat Transfer From Ionized Gases," Space Programs Summary 37-23, Vol. IV, pp 109-118, JPL, October 31, 1963.

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JPL Job No. 329-10701-1-3931
3-9-65

PLASMA HEAT TRANSFER
NASA Work Unit 129-01-09-04
JPL 329-10701-1-3831

EFFECT OF MAGNETIC AND ELECTRIC FIELDS ON HEAT TRANSFER

Installation of power cables to the Building 107 test area has been completed. Experiments pertaining to the influence of electric and magnetic fields on heat transfer from ionized gas flows are to be conducted at this location. An electromagnet has been properly oriented and mounted on the thrust stand. The vacuum duct with quartz windows to be used as part of this installation has been designed and fabricated. It is now being installed. Fabrication of a test stand to support the plasma generator and the installation of coolant lines, a gas supply line, and rotameters will be done later. It is anticipated that preliminary experiments with applied magnetic fields will be conducted during the second half of FY 1966.

INFLUENCE OF SWIRL ON HEAT TRANSFER

Experiments of heat transfer from ionized argon flows have thus far been limited to measurements of heat flux distributions to the electrodes of arc plasma generators, mixing chambers, nozzles, and diffusers pending the completion of the Building 107 test facility. Significantly higher heat fluxes have been found to occur in the convergent part of a convergent-divergent nozzle for swirling flows than for flows without swirl (Ref. 1). Swirl is often introduced into arc heads to improve performance. To more easily evaluate the influence of swirl on fluid dynamic parameters that affect heat transfer, tests are being conducted of argon flows at room temperature in conjunction with the ionized gas flow tests. Cold flow tests conducted in the apparatus without electrodes present, as shown in Fig. 1, indicate that the ratio of the tangential velocity to axial velocity is very high in the convergent part of the nozzle, as shown in Fig. 2. Furthermore, this velocity ratio decreases as the flow progresses through the nozzle. Because convective heat transfer is proportional to mass flux, this velocity ratio indicates that high heat fluxes would be expected in the convergent region when swirl is present. The tangential and axial velocity components were determined from temperature and static pressure measurements along the end wall and static pressure measurements along the nozzle wall. To compute the velocities, it was assumed that boundary layers were thin and that viscous forces and radial components of velocity were negligible. Velocity distributions upstream of the nozzle and along the nozzle are shown in Fig. 3. A more detailed discussion of these results is given in Ref. 2.

HEAT TRANSFER TO NOZZLES, MIXING CHAMBERS, AND DIFFUSERS

The next series of heat transfer tests will be started about the beginning of FY 1966 with two hohlraums in the mixing chamber and with the arc head located around a corner from the nozzle, as shown in Fig. 4. The hohlraums (one with a quartz window and one without a window) will be used to measure the thermal radiation from the gas. The electrodes are located so that the apparatus downsteam cannot view the arc. The dummy cathode shown in Fig. 4 contains pressure taps and was used for initial cold flow tests. These cold flow results show that (even though the gas was injected tangentially and, hence, a comparatively strong vortex existed in the cathode housing) there was no evidence of swirl after the gas had turned the

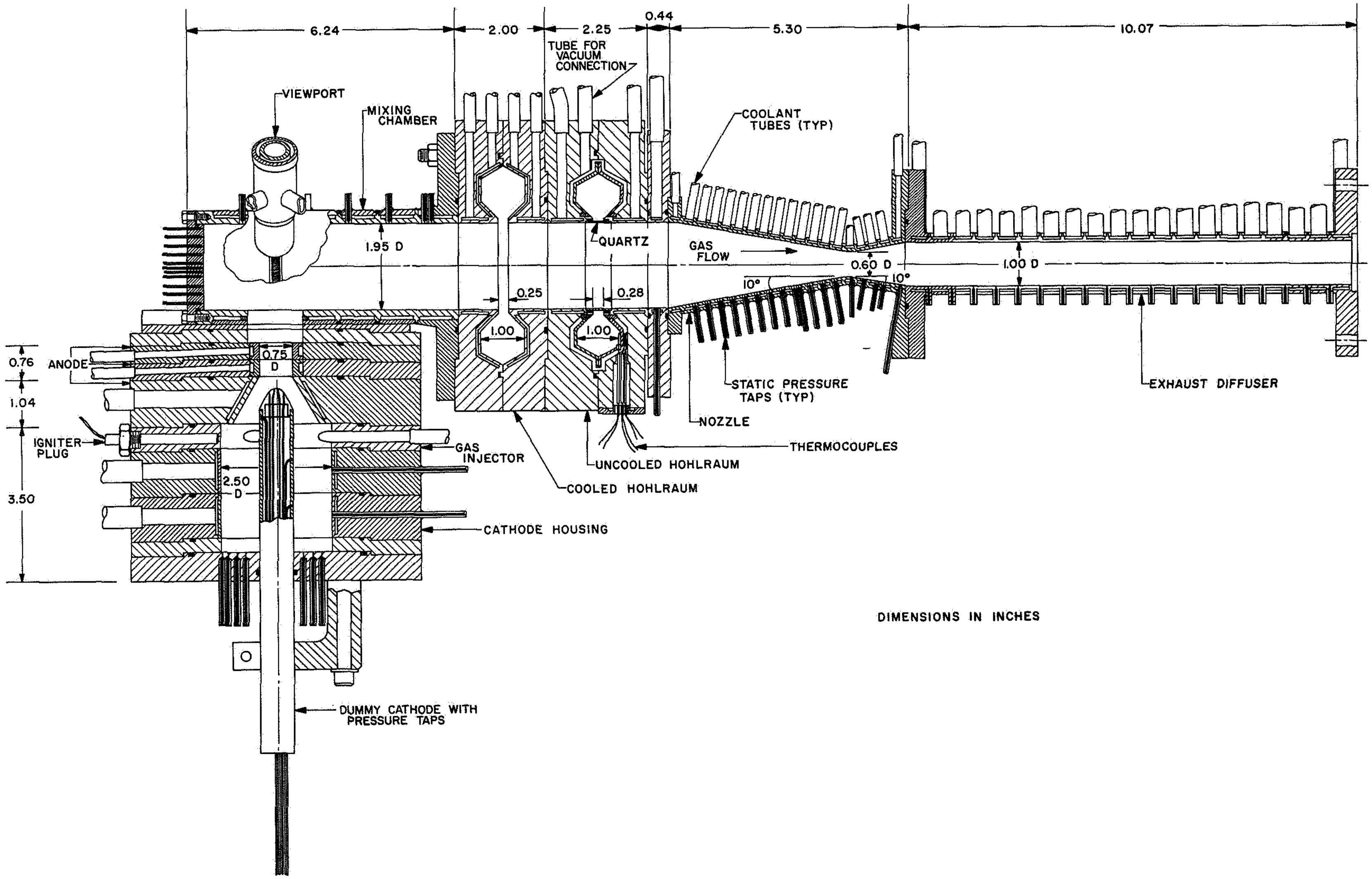


Fig. 1. Swirl flow test apparatus

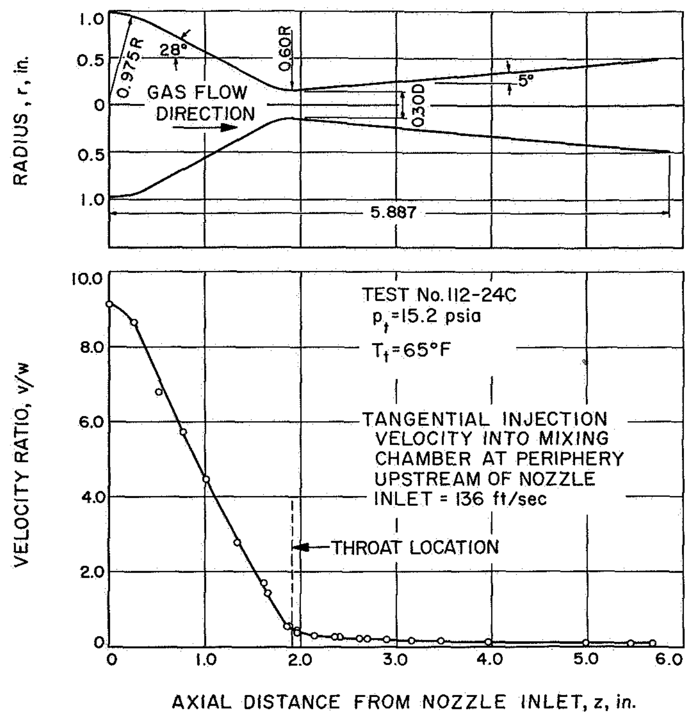


Fig. 2. Ratio of tangential to axial velocity distribution along 0.3 in. D_{th} nozzle for argon flow with swirl

corner. The dummy cathode has been replaced by a tungsten cathode without pressure taps, which will be used for the heat transfer tests that will follow. It is anticipated that spectroscopic and probe measurements will be made during some of these tests.

PUBLICATIONS, PRESENTATIONS, AND MEETINGS

The paper on the laminar boundary layer analysis (Ref. 3) that was discussed in the first Quarterly Progress Review for FY 1965 has been accepted for presentation at the 8th National Heat Transfer Conference, Los Angles, August 8-11, 1965.

The work of the Plasma Heat Transfer investigations was given before the NASA Research Advisory Committee on Fluid Mechanics at JPL May 6, 1965. This work was also discussed with Dr. Robert W. Graham, Head, Experimental Section, Lewis Research Center, and his associates.

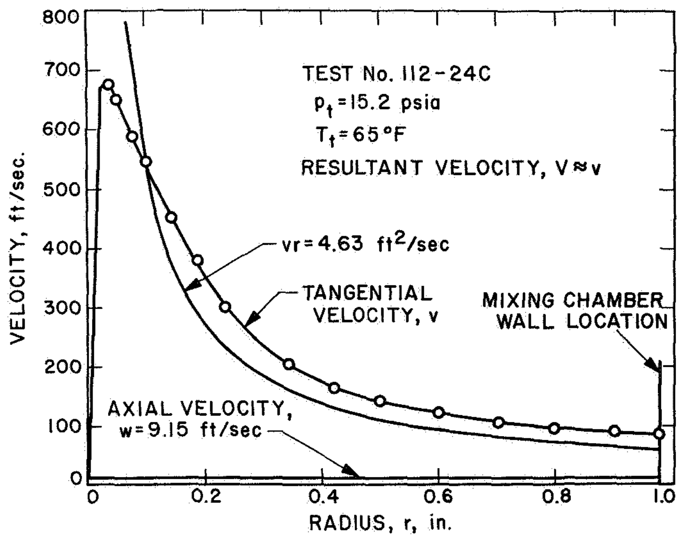


Fig. 3a. Velocity distributions for 0.3 in. D_{th} nozzle for argon flow with swirl
a) At inlet through constant-diameter mixing chamber

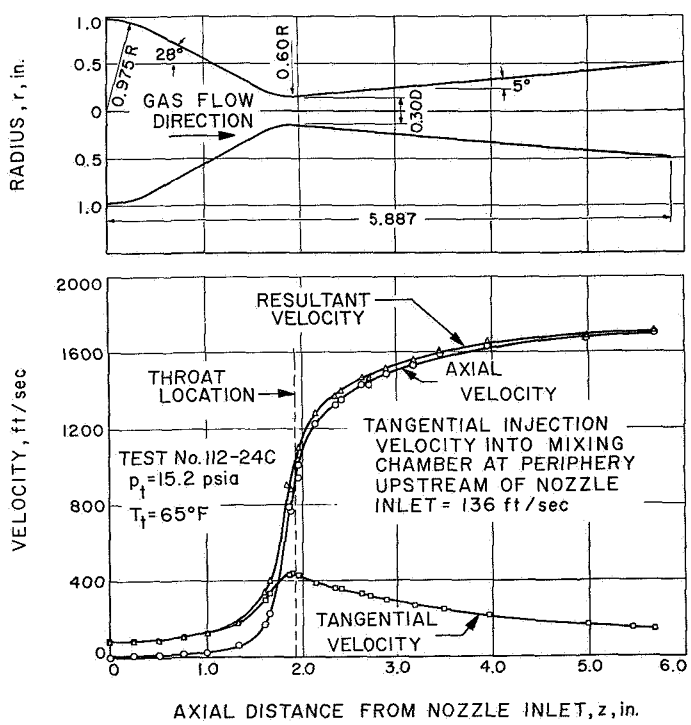


Fig. 3b. Velocity distributions for 0.3 in. D_{th} nozzle for argon flow with swirl
b) Along nozzle

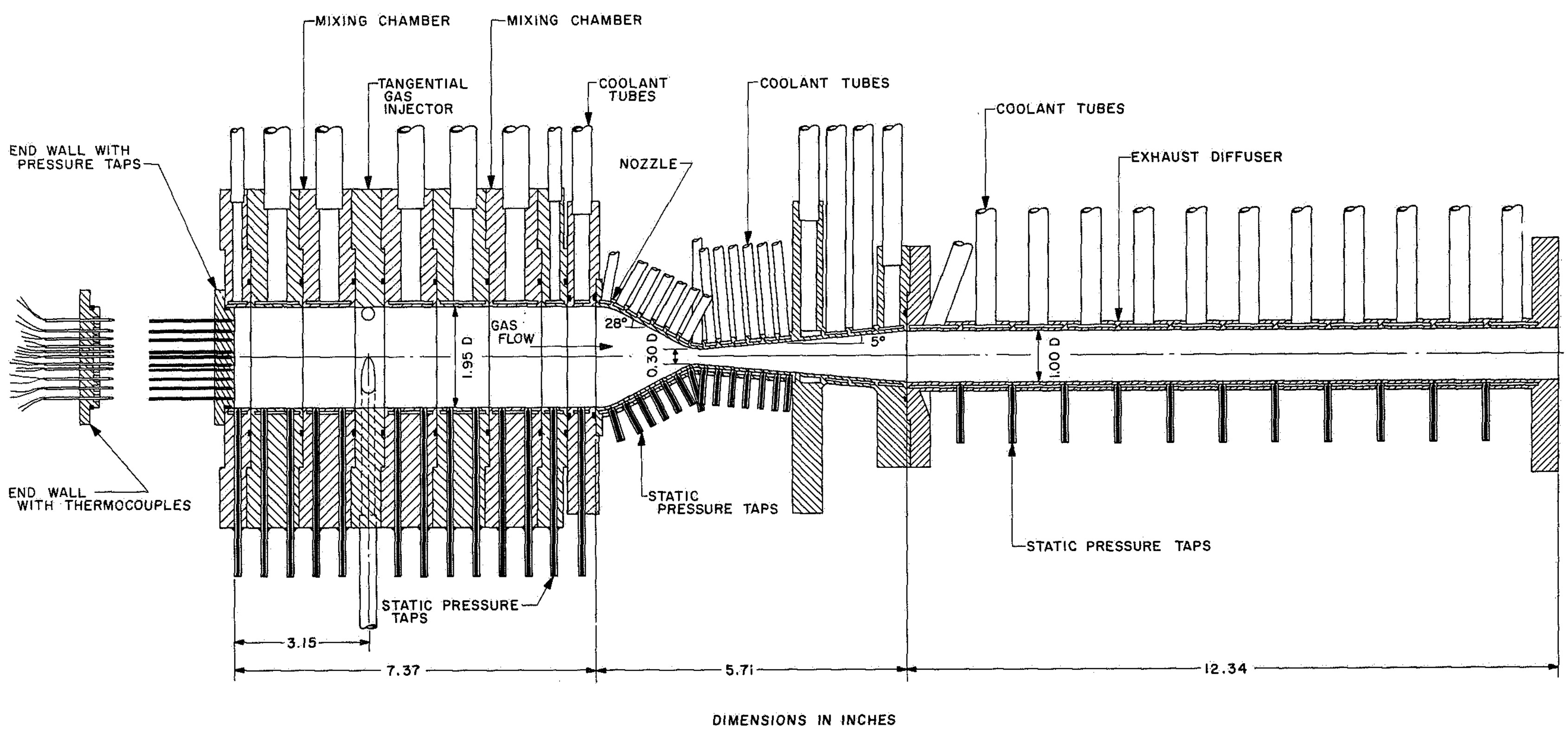


Fig. 4. Ionized gas heat transfer test apparatus

REFERENCES

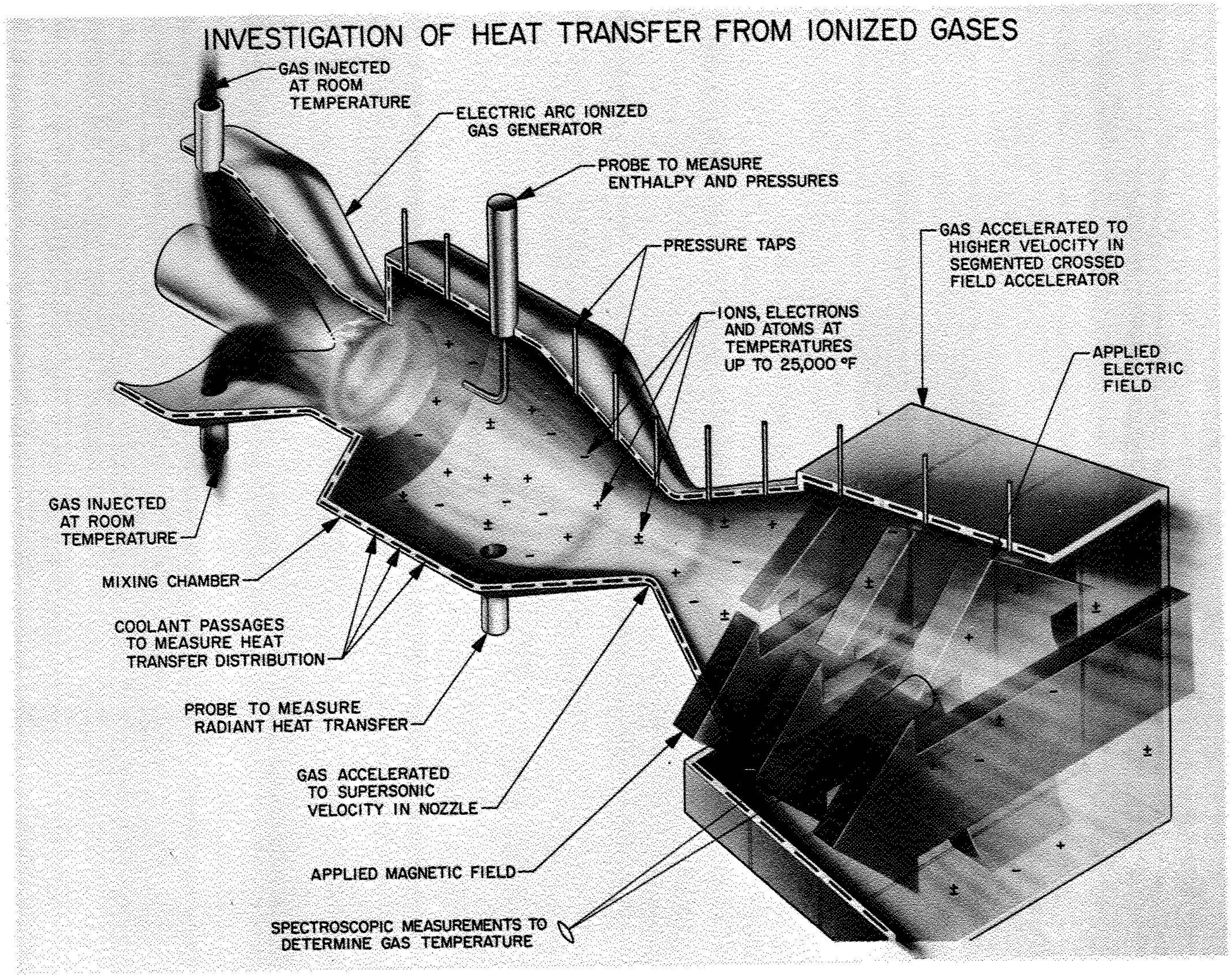
1. Massier, P. F., Heat Transfer to Convergent-Divergent Nozzles from Ionized Argon, Space Programs Summary 37-24, Vol. IV, pp. 105-108, Jet Propulsion Laboratory, Pasadena, California, December 31, 1963.

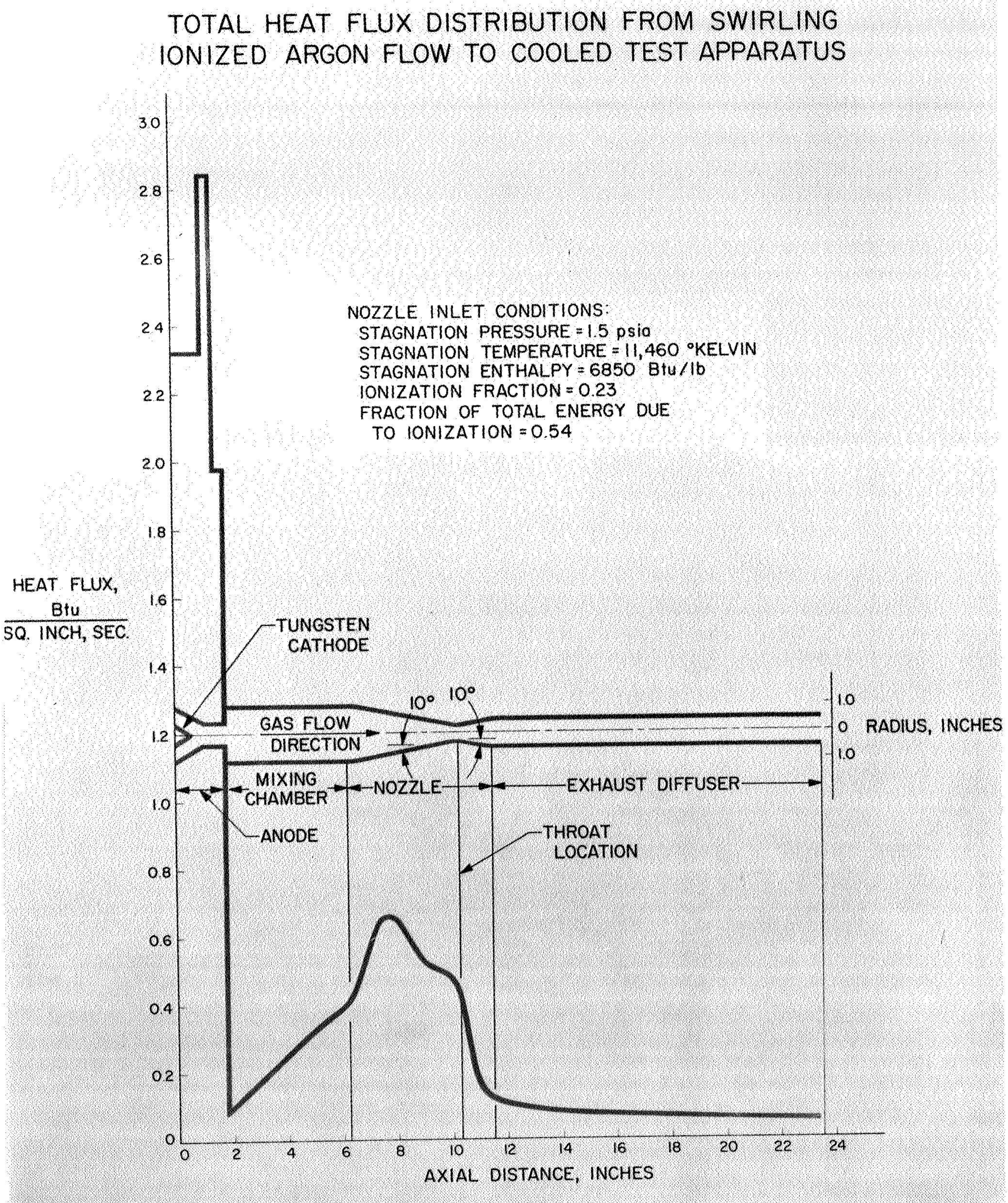
2. Massier, P. F., Axisymmetric Steady Flow of a Swirling Compressible Fluid Through a Convergent-Divergent Nozzle Without External Heat Transfer, Space Programs Summary 37-33, Vol. IV, Jet Propulsion Laboratory, Pasadena, California (to be published).

3. Back, L. H. and Witte, A. B., Prediction of Heat Transfer from Laminar Boundary Layers with Emphasis on Large Free-Stream Velocity Gradients and Highly Cooled Walls, Technical Report No. 32-728, Jet Propulsion Laboratory, Pasadena, California, June 1, 1965. Also, ASME Paper No. 65-H-39.

PLASMA HEAT TRANSFER
OBJECTIVES

1. TO GAIN AN UNDERSTANDING OF THE CONVECTION AND RADIATION HEAT TRANSFER PHENOMENA ASSOCIATED WITH IONIZED GASES FLOWING UNDER THE INFLUENCE OF PRESSURE GRADIENTS, MAGNETIC FIELDS AND ELECTRIC FIELDS.
2. TO CORRELATE EXPERIMENTAL RESULTS.
3. TO DEVELOP A METHOD FOR PREDICTING LOCAL HEAT TRANSFER RATES FROM IONIZED GASES FLOWING UNDER THESE CONDITIONS.


INVESTIGATION OF HEAT TRANSFER FROM IONIZED GASES
GAS INJECTED AT ROOM TEMPERATURE
ELECTRIC ARC IONIZED GAS GENERATOR
PROBE TO MEASURE ENTHALPY AND PRESSURES
PRESSURE TAPS
IONS, ELECTRONS AND ATOMS AT TEMPERATURES UP TO 25,000 °F
GAS ACCELERATED TO HIGHER VELOCITY IN SEGMENTED CROSSED FIELD ACCELERATOR
APPLIED ELECTRIC FIELD
GAS INJECTED AT ROOM TEMPERATURE
MIXING CHAMBER
COOLANT PASSAGES TO MEASURE HEAT TRANSFER DISTRIBUTION
PROBE TO MEASURE RADIANT HEAT TRANSFER
GAS ACCELERATED TO SUPERSONIC VELOCITY IN NOZZLE
APPLIED MAGNETIC FIELD
SPECTROSCOPIC MEASUREMENTS TO DETERMINE GAS TEMPERATURE



TOTAL HEAT FLUX DISTRIBUTION FROM SWIRLING IONIZED ARGON FLOW TO COOLED TEST APPARATUS
NOZZLE INLET CONDITIONS:
STAGNATION PRESSURE = 1.5 psia
STAGNATION TEMPERATURE = 11,460 °KELVIN
STAGNATION ENTHALPY = 6850 Btu/lb
IONIZATION FRACTION = 0.23
FRACTION OF TOTAL ENERGY DUE TO IONIZATION = 0.54
HEAT FLUX, Btu / SQ. INCH, SEC.
TUNGSTEN CATHODE
GAS FLOW DIRECTION
10°
10°
1.0
0
1.0
RADIUS, INCHES
MIXING CHAMBER
NOZZLE
EXHAUST DIFFUSER
ANODE
THROAT LOCATION
AXIAL DISTANCE, INCHES

PLASMA HEAT TRANSFER

PRESENT INVESTIGATION INCLUDES:

1. STEADY FLOW OF THERMALLY IONIZED ARGON.
2. LAMINAR, TRANSITIONAL AND TURBULENT FLOWS.
3. AVERAGE STAGNATION TEMPERATURES AT THE NOZZLE INLET BETWEEN APPROXIMATELY 2,000 AND 12,000 K.
4. STAGNATION PRESSURES BETWEEN 1.0 PSIA AND 40 PSIA.
5. AVERAGE IONIZATION FRACTIONS AT THE NOZZLE INLET UP TO APPROXIMATELY 0.3.

PLASMA HEAT TRANSFER

PRESENT INVESTIGATION INCLUDES:

6. MEASUREMENT OF WALL STATIC PRESSURES AND COMBINED HEAT TRANSFER RATE DISTRIBUTIONS ALONG THE WALLS OF ARC JET ELECTRODES, MIXING CHAMBERS, NOZZLES AND EXHAUST DIFFUSERS. COMBINED HEAT TRANSFER RATE INCLUDES CONVECTION AND THERMAL RADIATION.

7. MEASUREMENT OF THE RATE OF THERMAL RADIANT ENERGY TRANSFERRED TO THE WALL OF A MIXING CHAMBER. THIS IS ACCOMPLISHED BY USE OF HOHLRAUMS.

PLASMA HEAT TRANSFER

PRESENT INVESTIGATION INCLUDES:

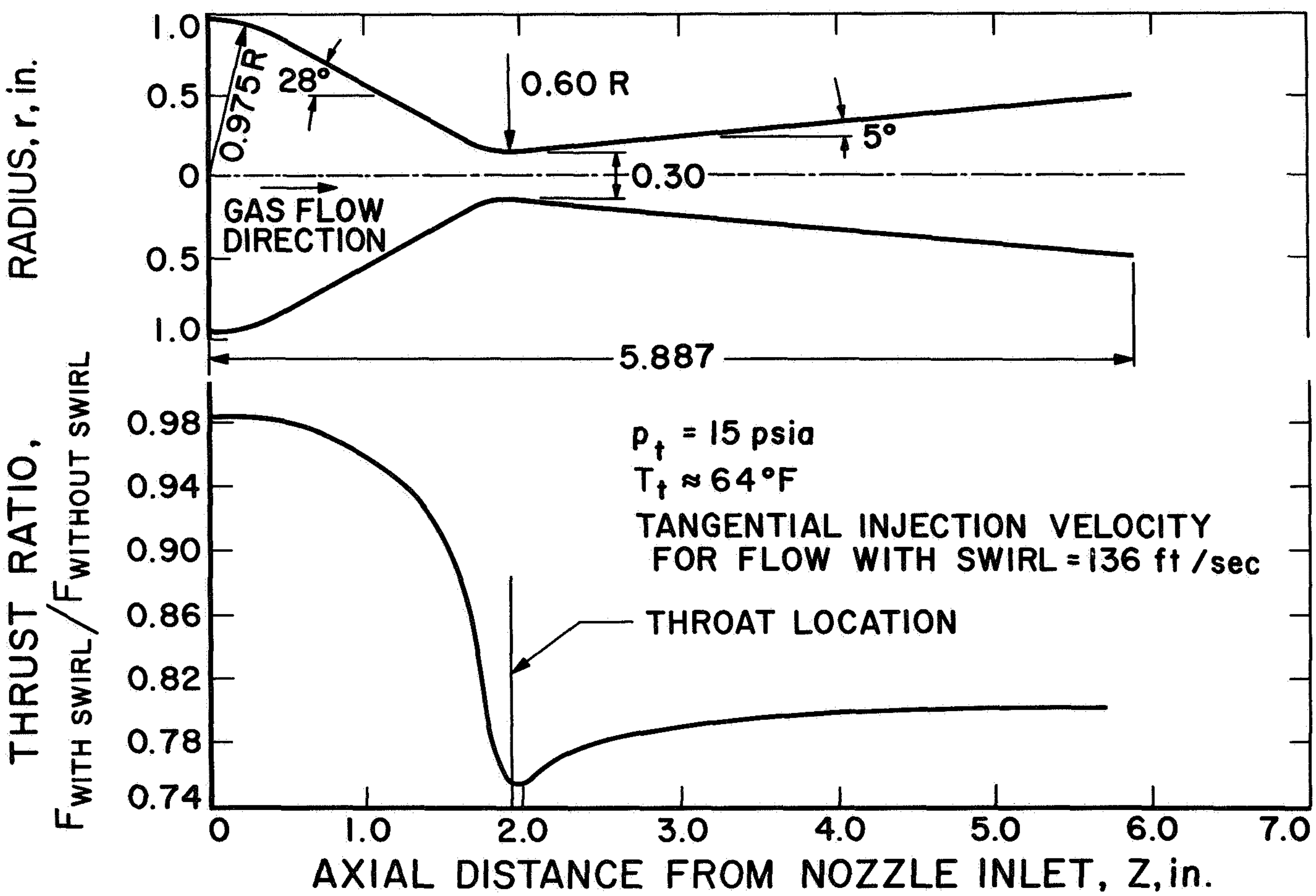
9. COMPARISONS OF EXPERIMENTAL HEAT FLUX DISTRIBUTIONS FOR FLOWS WITH SWIRL AND WITHOUT SWIRL.

10. MEASUREMENT OF TEMPERATURE AND STATIC PRESSURE DISTRIBUTIONS ALONG THE WALLS OF THE TEST APPARATUS USING ARGON FLOW AT ROOM TEMPERATURE IN ORDER TO GAIN A BETTER UNDERSTANDING OF SWIRLING FLOW FIELDS.

11. ANALYSES OF SWIRLING FLOWS THROUGH NOZZLES.

12. SPECTROSCOPIC MEASUREMENTS IN THE JET LEAVING THE TEST APPARATUS, THE MIXING CHAMBER AND THE ARC TO DETERMINE EQUILIBRIUM ELECTRON CONCENTRATION AND GAS TEMPERATURE.

DISTRIBUTION OF THE RATIO OF THRUST WITH SWIRL TO THRUST WITHOUT SWIRL FOR ARGON FLOW THROUGH A CONVERGENT-DIVERGENT NOZZLE



PLASMA HEAT TRANSFER

ANTICIPATED FUTURE EXPERIMENTAL INVESTIGATIONS:

1. MEASUREMENTS OF THERMAL RADIATION DISTRIBUTIONS WITH A COOLED PROBE.

2. STAGNATION ENTHALPY, STAGNATION PRESSURE AND STATIC PRESSURE DISTRIBUTION MEASUREMENTS UPSTREAM AND DOWNSTREAM OF NOZZLES WITH PROBES.

3. HEAT TRANSFER RATE AND PRESSURE MEASUREMENTS IN CHANNELS WITH APPLIED ELECTRIC AND MAGNETIC FIELDS. USE OF A RADIATION-COOLED NOZZLE.

4. USE OF GASES OTHER THAN ARGON.

JPL Job No. 329-11101-1-3832

RESEARCH AND TECHNOLOGY RESUME	1.	2. GOVT. ACCESSION	3. AGENCY ACCESSION NR 000560	
4. DATE OF RESUME 01-04-65	5. KIND OF RESUME D Change	6. SECURITY U RPT U WRK	7. REGRADING N/A	8. RELEASE LIMITATION NL	9. LEVEL OF RESUME A. Work Unit

10a. CURRENT NUMBER/CODE 129-01-04-01-55

10b. PRIOR NUMBER/CODE

11. TITLE: Plasma Sources, Generators and Accelerators

12. SCIENTIFIC OR TECH. AREA 006400 Fluid Mech., 013000 Plasma Physics, 005400 Elect. Prop.

13. START DATE 07-61

14. CRIT. COMPL. DATE N/A

15. FUNDING AGENCY NR OTHER

16. PROCURE. METHOD C. In-House

17. CONTRACT/GRANT a. DATE b. NUMBER N/A c. TYPE d. AMOUNT

18. RESOURCES EST.	a. PROFESSIONAL MAN-YEARS	b. FUNDS (In thousands)
PRIOR FY—65	1.7	203
CURRENT FY—66	1.3	180

19. GOVT. LAB/INSTALLATION/ACTIVITY
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RESP. INDIV.: D. R. Bartz/G.R. Russell
TEL: 213-354-4060

20. PERFORMING ORGANIZATION
NAME: N/A
ADDRESS:
INVESTIGATORS PRINCIPAL:
ASSOCIATE:
TEL: TYPE:

21. TECHNOLOGY UTILIZATION

22. COORDINATION

23. KEYWORDS

24. Objectives: To develop several types of plasma sources capable of producing large volumes of high energy, steady-state plasma to be utilized in the study of transport phenomena, inelastic rate processes, and shock wave structure. To develop a basic understanding of the operation of nonequilibrium MHD accelerators and generators. Generator and accelerator research is directly related to the areas of space power generation and electrical propulsion.

25. Approach: Work with the following types of devices has been started in FY 65, and will be continued in FY 66:

(1) Cross-field accelerator (constant pressure - 1 mm Hg)
(2) MPD arc (with and without containment)

Both the cross-field accelerator and MPD arc will be utilized as plasma sources, as well as studies to determine the efficiency, maximum limits of acceleration, and limits on operational lifetime. Shock tube studies of both an accelerator and generator will be initiated during FY 66. Tests will be conducted at pressures of up to 10 atms. where the radiation is self-absorbed.

26. Progress: Acceleration ratios of the order of two at thermal efficiencies of 70% have been achieved with a single stage cross-field accelerator. Electron temperature and density, velocity and total pressure measurements have been made in the accelerator exhaust. Experimental results are in agreement with theory, indicating that the accelerated plasma is far from equilibrium. An MPD arc has been designed and tested. Extensive diagnostics of the arc exhaust have been completed. A part of the work will be reported in a paper given at the summer (San Francisco) meeting of the AIAA, entitled, "Electron Density and Temperature Measurements in the Exhaust of an MPD Arc," by A. Kelly, J. Gardner, and N. Nerheim.

27.	28. REQUESTING AGENCY	29. INTER-CENTER SUPPORT	30. CROSS CODE

31. SPECIAL EQUIPMENT

32. FUNDS ($ K)	IN-HOUSE	CONTRACT
PRIOR FY—65	203	N/A
CURRENT FY—66	180	N/A
NEXT FY—		

33. UNIQUE PROJECT Research Program, SRT

34. SUB PROGRAM Fluid Physics Research

35. TASK AREA Plasma Generation

NASA FORM 1122 (AUGUST 64)
(Items 1 to 28 identical to DD Form 1498)

(OVER)

F 3

CONTINUATION SHEET

Description of FY66 Work Unit, Objectives, Approach and Progress

129-01-04-01-55
PLASMA SOURCES, GENERATORS AND ACCELERATORS
D. R. Bartz, G. R. Russell

Objectives

The primary objective is to produce several types of plasma sources capable of producing large volumes of high energy, steady-state plasma to be utilized in the study of transport phenomena, inelastic rate processes, and shock wave structure. A secondary objective is to develop a basic understanding of the operation of non-equilibrium MHD accelerators and generators. Generator and accelerator research is directly related to the areas of space power generation, electrical propulsion, and high energy wind tunnel simulation.

Approach

In FY65 attention has been focused on two types of devices - the cross-field accelerator and the MPD (Ducati) arc. The first phase of the cross-field accelerator work at pressures of approximately 1mmHg has been completed. It is thought that the performance can be appreciably improved by using segmented electrode geometry, applied axial electric fields and most importantly, by a precise controlling of the applied magnetic field. Therefore, the accelerator is now being modified and experiments will be started with the modified accelerator section in the first quarter of FY66.

Work will be continued to determine the operating limits of the water-cooled MPD arc and to determine the plasma properties in the arc exhaust. In addition, a partially water cooled MPD arc with and without porous electrodes is being designed, with little or no mechanical containment. Experiments with this arc will be started in the last quarter of FY65 and continued in FY66. The exhaust of four of the water cooled arcs operated simultaneously will be used as a plasma source for the shock wave studies.

Theoretical work indicates that both MHD power generation and cross-field acceleration is possible utilizing inert gases without seeding at high pressures and low inlet temperatures where the radiation produced by electromagnetically induced nonequilibrium ionization is self-absorbed. To determine the feasibility of this concept, both generator and accelerator tests will be conducted in a shock tunnel. One test section will be constructed for both tests. The shock tunnel is currently available as part of the Shock Tube Laboratory at JPL.

Progress

Accelerator ratios of the order of two at thermal efficiencies of 60 - 70% have been achieved with a single stage, constant pressure cross-field accelerator. Electron temperature and density, velocity, and total pressure measurements have

184

been made in the accelerator exhaust. The experimental results are in qualitative agreement with theory, indicating that the accelerated plasma is far from equilibrium. It is believed that the length of the magnetic field region and the inability to control the magnetic field gradients at the accelerator entrance and exit are causing large kinetic energy losses. In addition, in a single stage device, the axial electric field cannot be adequately controlled. The accelerator is currently being modified to reduce these deleterious effects.

A water cooled MPD (Ducati) arc has been designed and tested. The arc has been operated over a current range of 100 to 4000 amperes covering a total input power range of 2.5 to 100 KW with argon mass flows of .05 to 1.5 gms/sec. Extensive diagnostics of the arc exhaust have been completed. The most important result of the diagnostic work is that the degree of ionization does not exceed 10%, indicating that at the measured electron temperatures of the order of 18,000°K, the exhaust gas is completely out of equilibrium. The diagnostic work will be reported in a paper to be given at the summer meeting of the AIAA.

Tests have begun with an open Ducati arc head utilizing porous electrodes. Preliminary results are excellent. A well collimated beam of plasma is formed and containment is achieved principally by the arc's self induced magnetic field. Large erosion rates of the porous carbon cathodes have been observed at high current levels. Several types of porous and slotted tungsten cathodes are currently being fabricatdd and will be used to attempt to limit the erosion rates to acceptable limits.

Papers published or to be published as a result of work conducted in FY65 are as follows:

Kelly, A., Gardner, J., Nerheim, N., "Electron Density and Temperature Measurements in the Exhaust of a MPD Arc," AIAA Paper No. 65-298, presented at AIAA Second Annual Meeting, San Francisco, Calif., July 1965, accepted for AIAA Journal.

Russell, G. R., "Nonequilibrium Flow in a Linear MHD Generator Utilizing an Inert Gas Without Seeding," International Symposium on MHD Power Generation, Paris, July 1964.

JPL Job No. 329-11101-1-3832
3-9-65

FLUID PHYSICS RESEARCH (129-01)

PLASMA SOURCES, GENERATORS, AND ACCELERATORS
NASA Work Unit 129-01-04-01
JPL 329-11101-1-3832

MAGNETO-PLASMA DYNAMIC (MPD) SOURCE

A water-cooled MPD plasma source, first described by Ducati, Gianinni, and Muehlberger (AIAA Journal, 1964), has been designed and tested in the latter half of FY 1965. The source has been operated over a current range of 100 to 4000 amp, covering a total input power range of 2.5 to 100 kw with argon mass flows of 0.05 to 1.5 gm/sec.

Extensive diagnostics of the source exhaust have been completed and are reported in Ref. 1. The most important results of the study are:

1. Gas enthalpy calculated from power input, cooling water losses, and gas flow measurements show that at the exit of the source the degree of ionization must be lower than equilibrium based on the spectroscopically determined electron temperature.

2. Immediately downstream of the source exit, impact probe measurements revealed the existance of a barrel shock closed by a normal shock. Downstream of this shock, impact and velocity probe measurements indicate that the Mach number of the plume is close to unity.

3. Measured electron density levels in the plume downstream of the shock region are orders of magnitude larger than electron densities calculated from the Saha equation using measured electron temperatures.

A thrust stand for use in a vacuum tank, at the MPD thrust level, has been designed and fabricated in the last quarter of FY 1965. In the first quarter of FY 1966, thrust measurements will be made with this thrust stand, coincident with the plume diagnostics. In particular, a correlation will be made between measured thrust and measured velocity in the plume to determine the magnitude of jet entrainment.

In the last half of FY 1965, tests were begun with an open MPD source using porous electrodes. Preliminary results indicate that a well collimated beam of plasma is formed, and containment is mainly achieved by the arc's self-induced magnetic field. Large erosion rates of the porous carbon cathodes have been observed at high current levels. Several types of porous and slotted tungsten cathodes are now being fabricated and will be tested in the first quarter of FY 1966 to attempt to limit the erosion rates to acceptable levels. In addition, velocity measurements in the plume will be made with and without material confinement to determine whether the flow can be accelerated at constant pressure to prevent shock formation downstream of the source exit.

ACCELERATOR-GENERATOR STUDY

A computer program to generate both nonequilibrium accelerator and generator flows will be completed in the first quarter of FY 1966. The program includes nonscalar electrical conductivity, nonequilibrium radiation, ionization and recombination rates, thermal conduction, charge exchange, and thermal-electric effects. Preliminary results obtained with a part of the program are reported in Ref. 2 and 3.

Results obtained from the computer program indicate that both MHD power generation and cross-field acceleration are possible using inert gases without seeding at low inlet temperatures (2000 to 3000°K corresponding to stagnation conditions in a nuclear reactor). To determine the feasibility of this concept, both generator and accelerator tests will be conducted with segmented constant pressure test sections.

Initially, steady-state tests will be conducted in a plasma vacuum facility. The test section design will be started in FY 1966 and fabrication should be completed in the second quarter of FY 1966. On completion of the test section and assembly of the necessary diagnostics, experiments will be initiated to determine the degree of electron temperature elevation and the resulting nonequilibrium radiation and ionization. The experimental results will be compared with the computer program described above.

PRESENTATIONS

The paper titled, Nonequilibrium Flows in Crossed Electric and Magnetic Fields, by G. R. Russell, was presented before the NASA Research Advisory Committee on Fluid Mechanics at JPL on May 6, 1965.

REFERENCES

1. Kelly, A. J., Nerheim, H. M., Gardner, J. A., Electron Density and Temperature Measurements in the Exhaust of a MPD Source, AIAA Second Annual Meeting and Technical Demonstration, San Francisco, California, July 26-29, 1965.

2. Russell, G. R., Nonequilibrium Flow in a Linear MHD Generator Utilizing an Inert Gas Without Seeding, International Symposium on MHD Power Generation, Paris, July 1964.

3. Russell, G. R., "The Effect of Electron Drift Velocities and Temperature Gradients in Nonequilibrium MHD Generators," Submitted to Physics of Fluids. June 1965.

JPL Job No. 329-11201-1-3832

RESEARCH AND TECHNOLOGY RESUME	1.	2. GOVT. ACCESSION	3. AGENCY ACCESSION NR 000563	
4. DATE OF RESUME 01-04-65	5. KIND OF RESUME D Change	6. SECURITY U RPT U WRK	7. REGRADING N/A	8. RELEASE LIMITATION NL	9. LEVEL OF RESUME A. Work Unit

10a. CURRENT NUMBER/CODE 129-01-05-04-55

10b. PRIOR NUMBER/CODE

11. TITLE: Plasma Transport Properties, Shock Waves, and Inelastic Rate Processes

12. SCIENTIFIC OR TECH. AREA	13. START DATE	14. CRIT. COMPL. DATE	15. FUNDING AGENCY
006400 Fluid Mech., 013000 Plasma Physics, 016700 Thermodynamics	07-64	N/A	NR OTHER

16. PROCURE. METHOD: C. In-House

17. CONTRACT/GRANT: a. DATE; b. NUMBER N/A; c. TYPE; d. AMOUNT

18. RESOURCES EST.	a. PROFESSIONAL MAN-YEARS	b. FUNDS (In thousands)
PRIOR FY—65	0.9	154
CURRENT FY—66	1.8	140

19. GOVT. LAB/INSTALLATION/ACTIVITY

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20. PERFORMING ORGANIZATION

NAME: N/A
ADDRESS:
INVESTIGATORS PRINCIPAL:
ASSOCIATE:
TEL: TYPE:

21. TECHNOLOGY UTILIZATION

22. COORDINATION

23. KEYWORDS

24. Objectives: To study experimentally transport phenomena, shock wave structure, and inelastic rate processes in partially ionized gases. Particular attention is focused on the nonequilibrium plasma where radiation can play an important role in inelastic rate processes and plasma instabilities can contribute to anomalies in the transport properties. Determination of shock structure, measurement of electron recombination rates, and the measurement of ionization rates in seeded inert gases will be emphasized in FY66.

25. Approach: Four experiments are planned for FY66:

1. Measurement of electron recombination rates - conducted in a discharge tube.
2. Determination of shock wave structure - in exhaust of an MPD arc.
3. Anomalous plasma diffusion - current experiment (FY65) will be extended to include magnetic fields of the order of 10^5 gauss.
4. Measurement of ionization rates in seeded inert gases - conducted in a heated shock tube.

Progress: Preliminary results have been obtained in a discharge tube of electron-ion
26. recombination rates in pure argon over an electron temperature range of $300 < T_e < 16000^oK$ and an electron density range of $10^9 < n_e < 10^{15}$. The results are in agreement with the theoretical work of Byron. The first part of the anomalous plasma diffusion study has been completed. The results are summarized in the following two papers:
Chen, C.J.,"Anomalous Diffusion And Instabilities Of An Argon Plasma In A Strong Magnetic Field", submitted to Physics of Fluids, also JPL TR 32-695.
Chen, C. J.,"Valid Condition For Kromers-Unsold Continuum Theory In A Nonequilibrium Plasma", submitted to Physics of Fluids

27.	28. REQUESTING AGENCY	29. INTER-CENTER SUPPORT	30. CROSS CODE

31. SPECIAL EQUIPMENT

32. FUNDS ($ K)	IN-HOUSE	CONTRACT
PRIOR FY—65	154	N/A
CURRENT FY—66	140	N/A
NEXT FY—		

33. UNIQUE PROJECT: Research Program SRT

34. SUB PROGRAM: Fluid Physics Research

35. TASK AREA: Plasma Dynamics

NASA FORM 1122 (AUGUST 64)
(Items 1 to 26 identical to DD Form 1498)

(OVER)

CONTINUATION SHEET

Description of FY66 Work Unit, Objectives, Approach and Progress

129-01-05-04-55
PLASMA TRANSPORT PROPERTIES, SHOCK WAVES, AND INELASTIC RATE PROCESSES
D. R. Bartz, G. R. Russell

Objectives

The overall objective is to study experimentally transport phenomena, shock wave structure, and inelastic rate processes in partially ionized gases. Particular attention is focused on the nonequilibrium plasma where radiation can play an important role in the inelastic rate processes, and plasma instabilities can contribute to anomalies in the transport properties. This research is directly related to the development of electrical propulsion device, MHD generators and high temperature wind tunnel simulators which operate almost entirely in a region where the working fluids (partially ionized gases) are not in equilibrium.

Determination of shock structure, measurement of electron recombination rates, and the measurement of ionization rates in seeded inert gases will be emphasized in FY66.

Approach

Four experiments are planned for FY66 - measurement of electron recombination rates, determination of shock wave structure, anomalous plasma diffusion, and the measurement of ionization rates in seeded inert gases.

Measurement of electron recombination rates in argon have been measured in a discharge tube during FY65. Measurements will be continued in FY66 in a larger 50 cm diameter tube, using several pure inert gases and mixtures of inert gases. In addition, in the regime of low electron temperatures and densities, dissociative recombination rates and the associated production rates of molecular ions will be determined where plasma diffusion can be definitely ruled out as a source of electron depletion.

A standing shock wave will be produced in the exhaust of four MPD arcs in the large plasma vacuum facility. It is expected that the shock wave thickness based on atom-atom collisions ahead of the shock will be of the order of several centimeters. The electron density gradients in and adjacent to the shock front will be measured by Thomson scattering from a giant pulsed laser. Electron temperatures will be measured using relative-line intensity techniques.

This measurement of ionization rates in seeded inert gases will be conducted in a heated shock tube, which will be designed and constructed during the latter half of FY66. It is anticipated that preliminary experiments can be starte

195

in the last quarter of FY66. Ionization rates will be measured at relatively low pressures where radiative losses from the plasma can affect the ionization mechanism. Therefore, both the rate of ionization and the accompanying radiation due to nonequilibrium effects will be measured. These results will be directly applicable to the design of MHD generators utilizing seeded inert gases at elevated electron temperatures.

The anomalous plasma diffusion experiment started in FY65 will be continued in FY66, utilizing several inert gases in addition to argon. The magnetic field will be increased to the order of 10^5 gauss, and the effect of electric fields applied perpendicular to the magnetic field will be studied.

Progress

Electron-ion recombination rates have been obtained in a discharge tube utilizing pure argon over an electron temperature range of $300 < T_e < 1600^{\circ}K$ and an electron density range of $10^9 < n_e < 10^{15}$. The mechanism is three body and radiative-three body recombination. The results are in agreement with the theoretical work of Byron.

Anomalous plasma diffusion has been measured in a discharge tube with varying confining magnetic fields and gas pressures. Measurements were taken only in the diffusion dominated regime. The most important result is that the diffusion is classical (ambipolar) with magnetic fields less than about 1000 gauss and varies as $1/B^2$. For fields exceeding 1000 gauss, the diffusion exceeds the classical values and varies as $1/B$. At the onset of the anomalous diffusion, instabilities appear in the plasma. These instabilities are shown to be due to the "universal instability". The most important results of this study are summarized in the following two papers:

Chen, C. J., "Anomalous Diffusion and Instabilities of Argon Plasma in a Strong Magnetic Field," submitted to Journal of Applied Physics, also JPL TR 32-695.

Chen, C. J., "Valid Condition for Kramers-Unsold Continuim Theory in a Nonequilibrium Plasma," submitted to the Physics of Fluids.

Chen, C. J., Comments on "Visible Continuum Emission from Shocked Noble Gases," Physics of Fluids, Vol. 8, No. 8, August 1965.

JPL Job No. 329-11201-1-3832
3-9-65

PLASMA TRANSPORT PROPERTIES, SHOCK WAVES AND INELASTIC RATE PROCESSES
NASA Work Unit 129-01-05-04
JPL 329-11201-1-3832

ELECTRON RECOMBINATION RATES

The discharge tube and associated equipment for the recombination rate experiment have been assembled and preliminary experiments have begun. A pyrex tube 60 cm long and 50 cm in diameter will be filled with gases (argon is now being used) at pressures from 1μ to 100μ. A capacitor bank (3000 J) is triggered to discharge through the tube. After the cessation of the discharge, the time rates of the decay of electron temperature and density are observed. The dimension of the discharge tube is so chosen to assure that the diffusion of the charged particles in the whole range of electron density (10^9 to $10^{15} cm^{-3}$) and electron temperature (300 to 16,000°K) produced in the discharge is negligible in comparison with that because of recombination. The electron density as a function of time is measured by observing the continuum radiation at 5530 Å and ion probe output. Both of these measurements are calibrated by using a microwave cutoff point. The electron temperature is measured by using the spectral line ratio method and the triple probe method. The high quantum number argon lines 4259 and 4158 Å are chosen in the temperature measurement to assure that their populations have Boltzmann distributions. The results of the electron density measurements obtained from continuum intensity and ion probe measurements agree within 30% throughout the duration of the decay when both data are normalized to the microwave cutoff point[1]. The electron temperature measurement by spectroscopic and probe methods cannot be made much below 4000°K for the conditions of the experiment. The electron temperature below 4000°K is obtained from an extrapolation by using the electron energy equation. The atom temperature has to be known to make such an extrapolation. Because of the high electron temperatures and densities attained in the initial discharge, an appreciable amount of energy is transferred to the atomic component of the plasma during and before the period when the recombination rates are measured. Because of the increase in the atom temperature, extrapolation of the electron temperature cannot be made assuming a final value for the atomic temperature. Therefore, work is being carried out to measure the plasma pressure so that the temporal behavior of the atom temperature can be determined. A strain gage pressure transducer has been used for this measurement. Because of its slow rise time, only the asymptotic portion of the pressure response is used to evaluate the atom temperature. Pressure gages with a rise time of better than 100μ sec at a pressure of the order of 1 mm Hg are required. A gage is being designed to satisfy the requirements mentioned above and testing will begin at the start of FY 1966. On completion of the pressure gage tests, electron recombination rates will be measured in the inert gases and inert gas mixtures. At low electron temperatures, where dissociative recombination is a possible recombination mechanism, a mass spectrometer will be used to measure the molecular ion production rate because this production rate may limit the dissociative recombination rate. Experiments using the mass spectrometer will not be started until the end of the first half of FY 1966.

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[1] Chen, C. J., "Anomalous Diffusion and Instabilities of Argon Plasma in a Strong Magnetic Field," submitted to Phys. Fluids, also JPL 32-695.

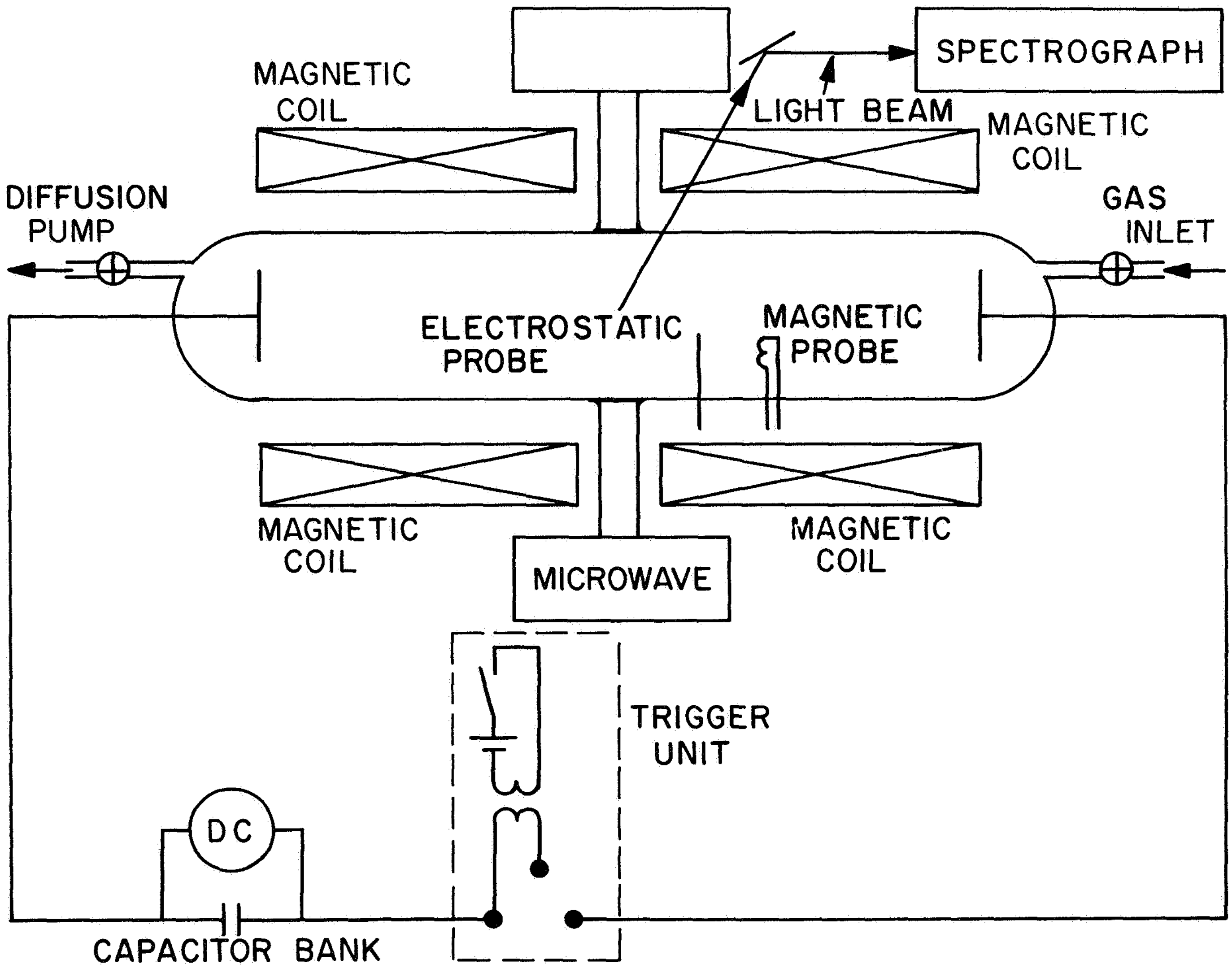
Three body-radiative recombination rates have been measured in argon over an electron temperature range of $1000 < T_e < 16,000°K$ and an electron density range of $10^9 < n_e < 10^{15}$ cm^{-3}. The data is in general agreement with the theoretical work of D. R. Bates, A. E. Kingston, and R. W. P. McWhirter (Proc. Roy. Soc., Vol. 267 and 270) and S. Bryon, R. C. Stabler, and P. I. Bortz (Phys. Rev. Let., Vol. 8, No. 8).

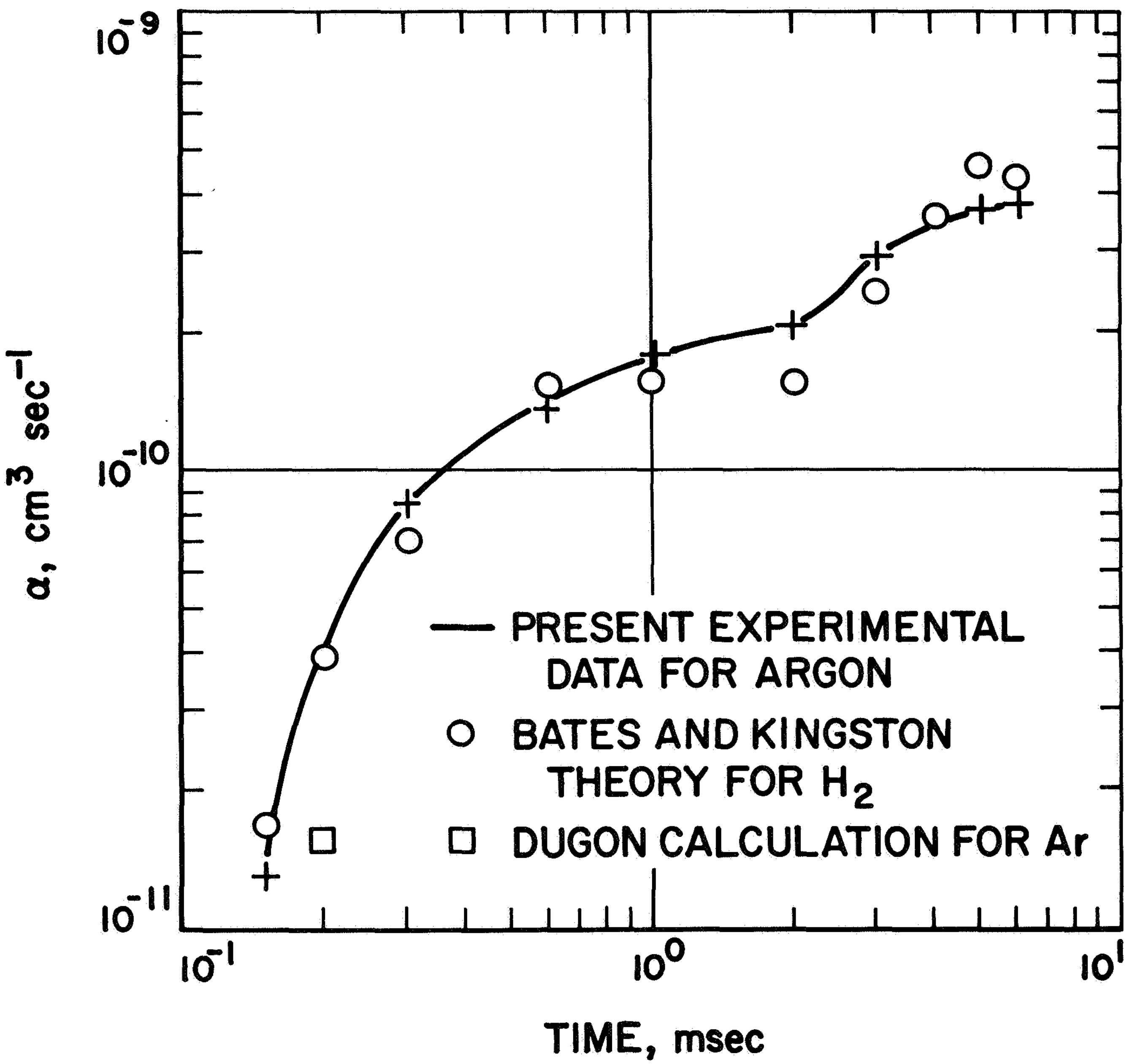
SHOCK WAVE STRUCTURE

In the first quarter of FY 1966, after completion of a feasibility study of using Thomson scattering of a laser beam to measure electron densities, an experiment will be undertaken to measure electron temperature and density gradients in and adjacent to a shock wave in a partially ionized gas. A standing shock wave will be produced in the exhaust of four MPD arcs in a vacuum plasma facility. It is expected that the shock wave thickness, based on atom-atom collisions ahead of the shock, will be of the order of several centimeters. The electron density gradients in and adjacent to the shock will be measured by Thomson scattering from a giant-pulsed laser. Electron temperatures will be measured using relative-line intensity techniques. The experimental work will be compared to the theory of M. Y. Jaffrin (Phys. Fluids, Vol. 8, No. 4).

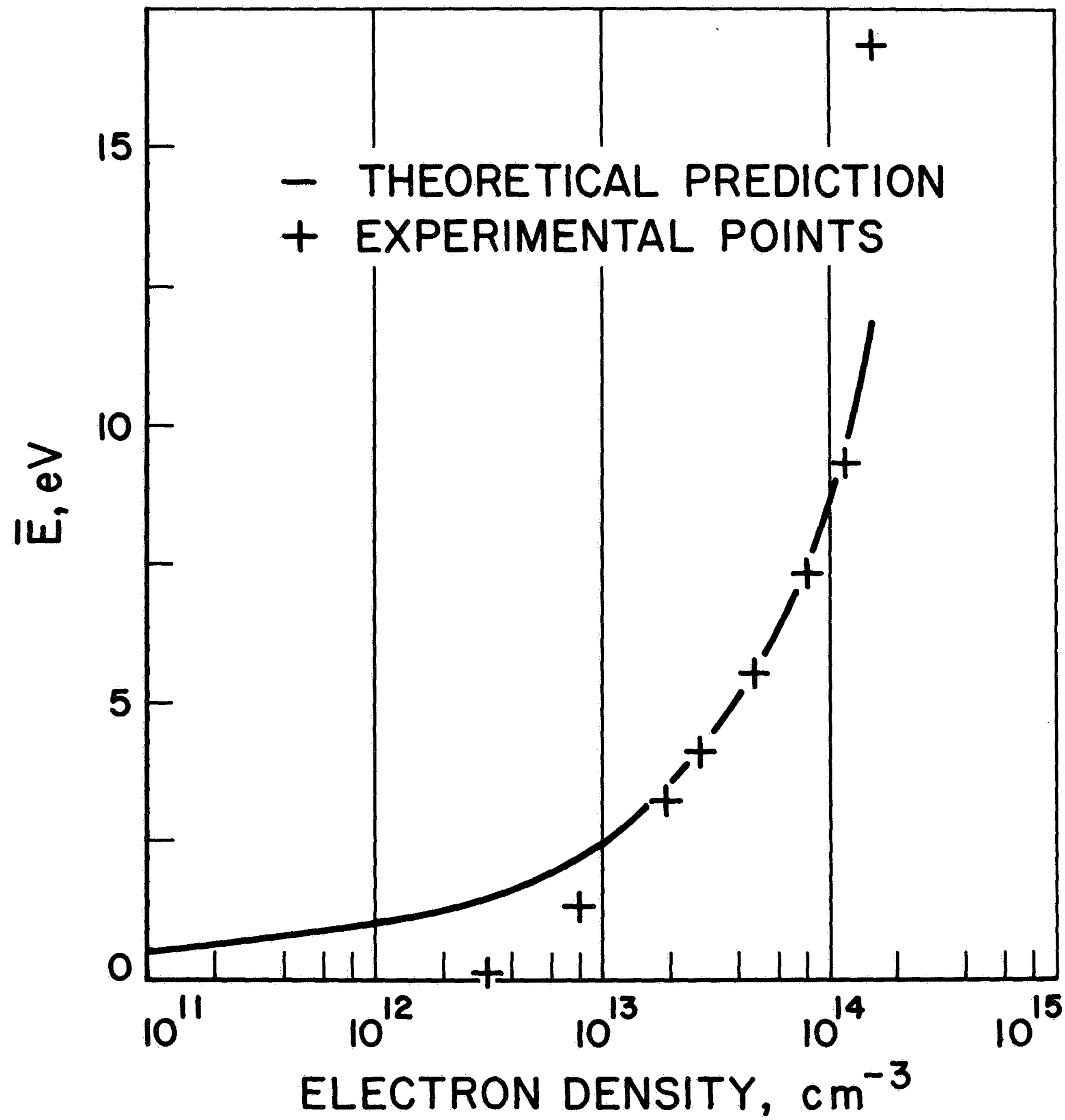
PRESENTATIONS

The paper titled, Anomalous Diffusion and Electron Recombination, by C. Chen was presented before the NASA Research Advisory Committee on Fluid Mechanics at JPL on May 6, 1965.

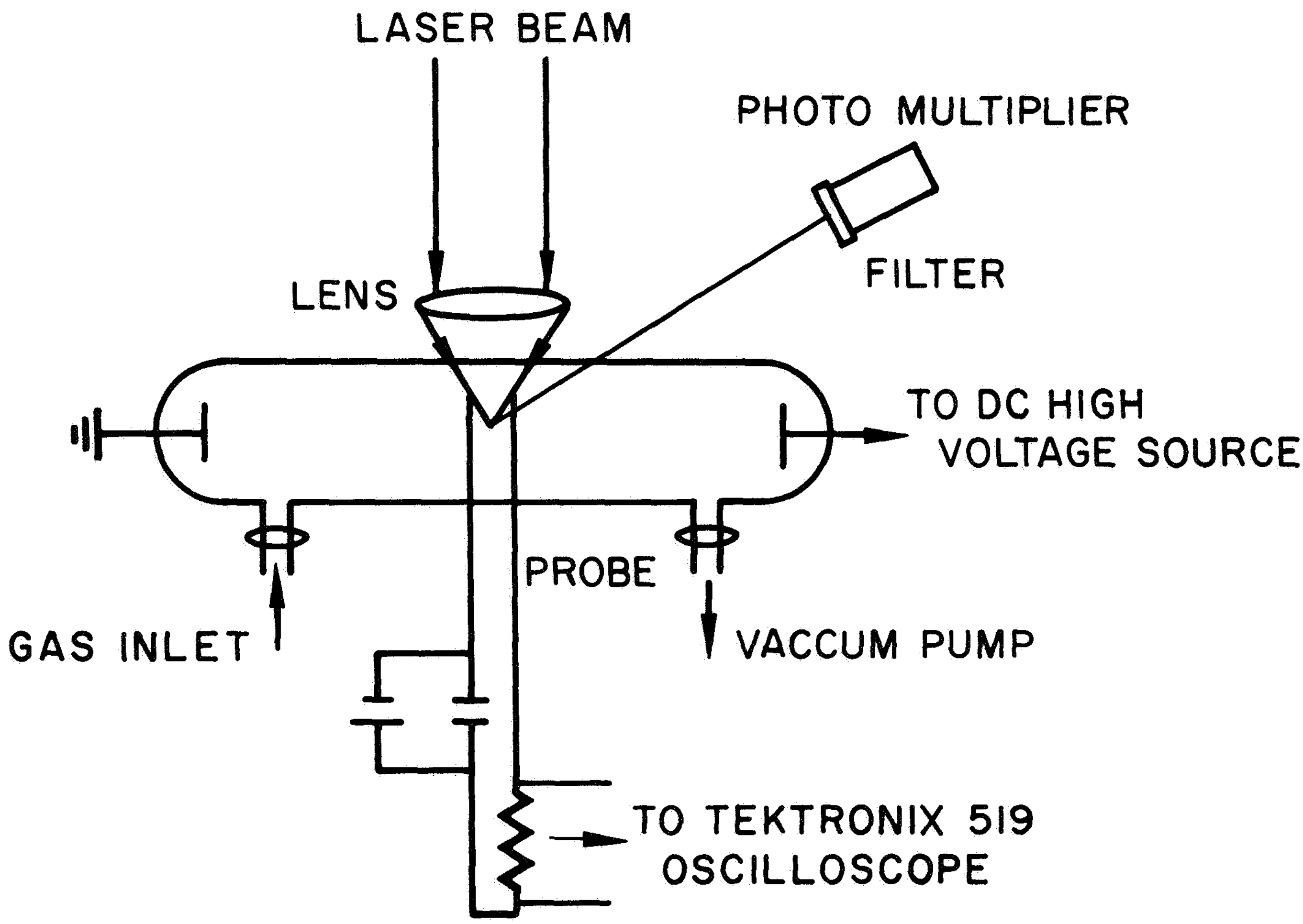

SPECTROGRAPH
MAGNETIC COIL
LIGHT BEAM
MAGNETIC COIL
DIFFUSION PUMP
GAS INLET
ELECTROSTATIC PROBE
MAGNETIC PROBE
MAGNETIC COIL
MICROWAVE
MAGNETIC COIL
TRIGGER UNIT
DC
CAPACITOR BANK



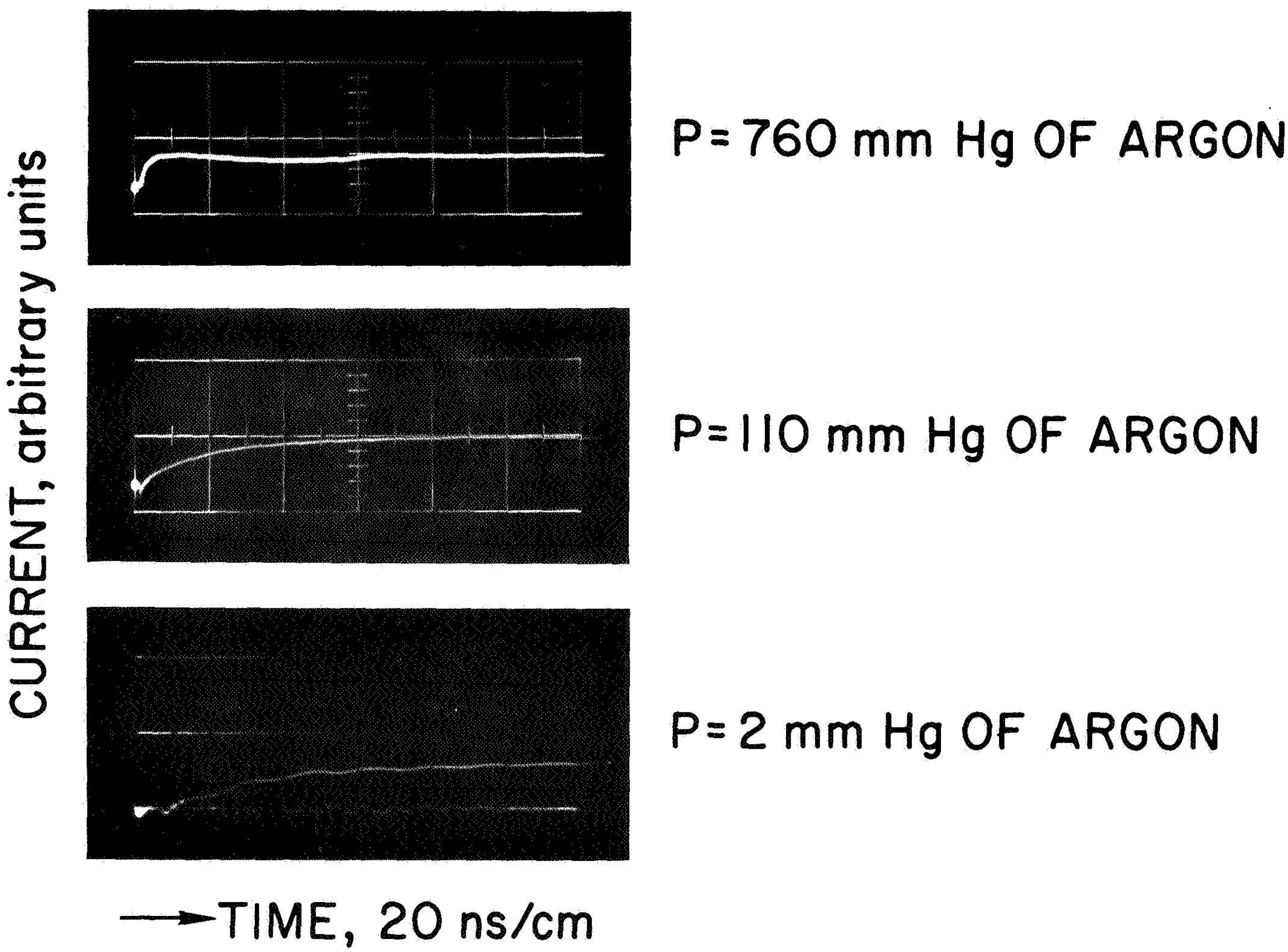
COEFFICIENT OF RECOMBINATION
FOR ARGON



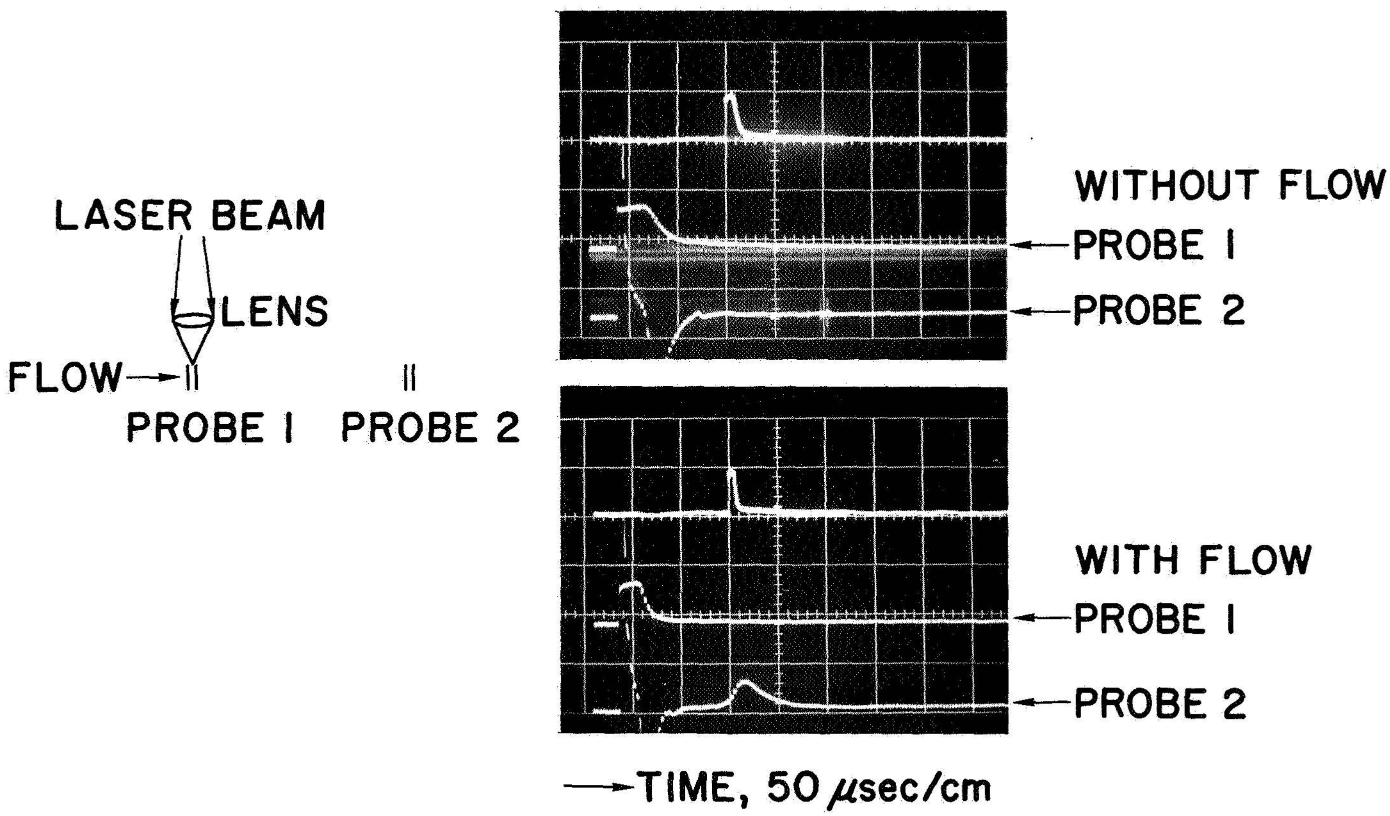
$\bar{E}$ AS FUNCTION OF ELECTRON DENSITY



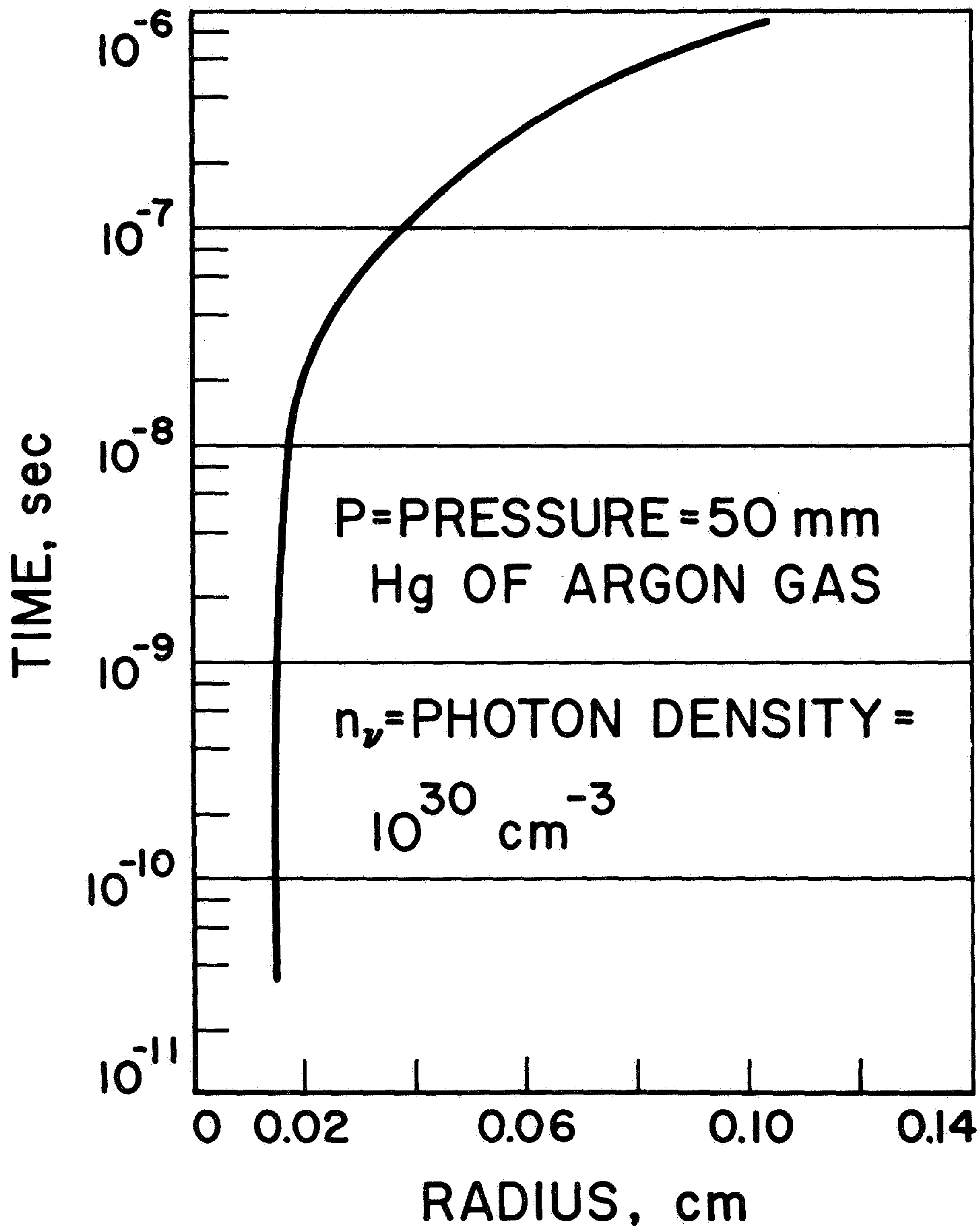
SCHEMATIC DIAGRAM FOR GAS BREAKDOWN BY LASER BEAM STUDY



ELECTRIC PROBE SIGNALS OF
STATIONARY PLASMA DROP



ELECTRIC PROBE SIGNALS OF MOVING PLASMA DROP

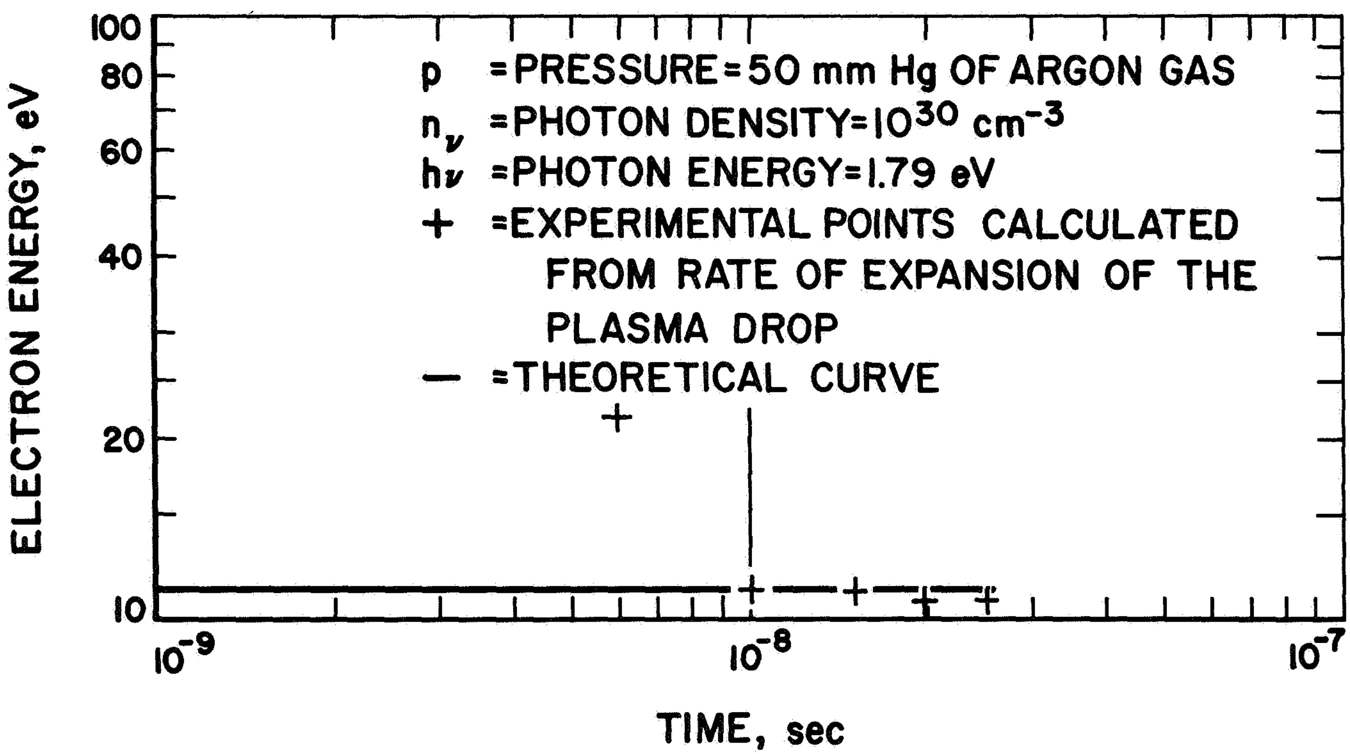


RADIUS OF PLASMA DROP AS FUNCTION OF TIME

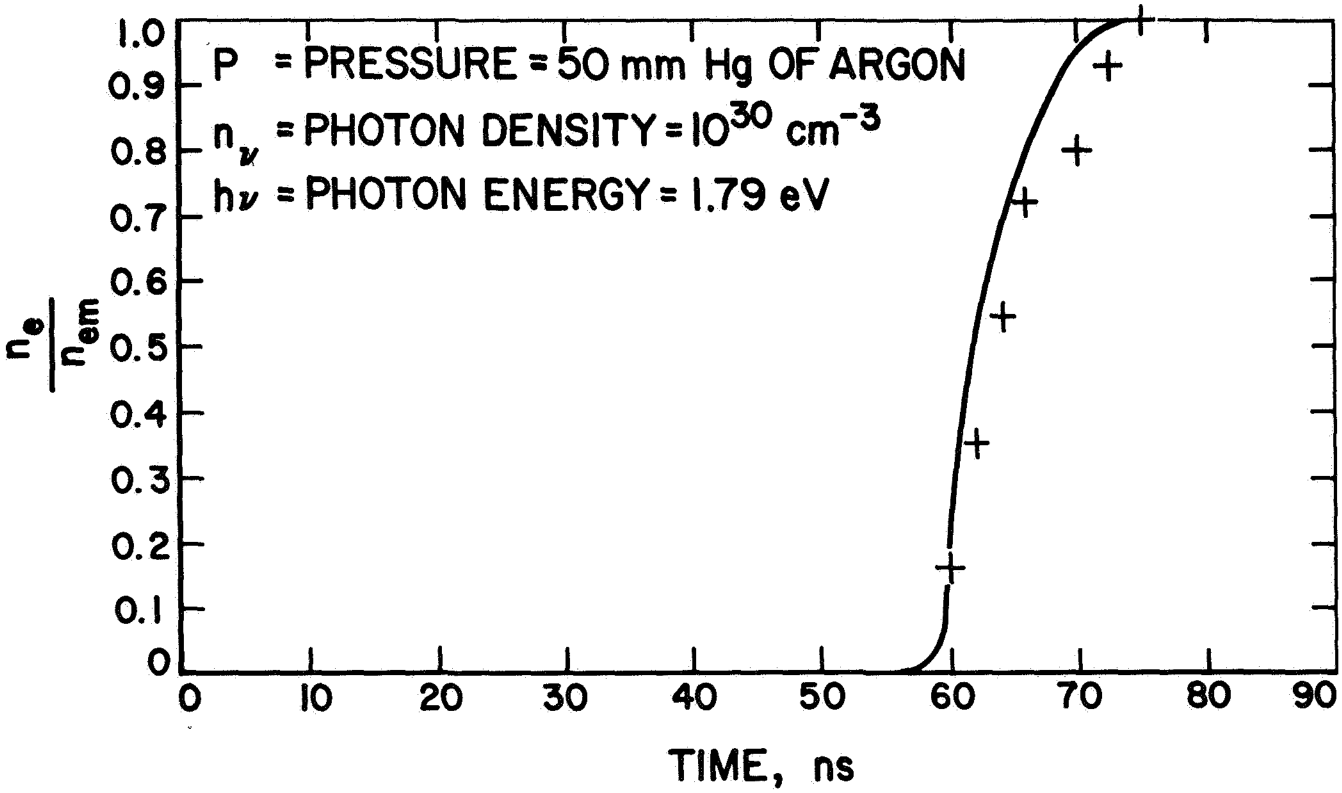
CONVECTIVE HEAT TRANSFER

PRESENT INVESTIGATION INCLUDES:

1. CONVECTIVE HEAT TRANSFER (NEGLIGIBLE RADIATION).
2. STEADY FLOWS
3. NON-REACTIVE FLOWS
4. TURBULENT FREE STREAM AND BOUNDARY LAYERS.
5. STAGNATION TEMPERATURES BETWEEN 500 AND 1500 DEG. F.
6. STAGNATION PRESSURES BETWEEN 20 AND 250 PSIA.



ELECTRON ENERGY AS FUNCTION OF TIME



ELECTRON DENSITY AS FUNCTION OF TIME

P mm Hg	RISE TIME (90% OF MAX) ns	
	CALCULATION	MEASURED
2	180	120
50	80	80
760	18	20

COMPARISON OF ELECTRON
DENSITY RISE TIME

JPL Job No. 329-11401-1-3832

RESEARCH AND TECHNOLOGY RESUME

1.	2. GOVT. ACCESSION	3. AGENCY ACCESSION NR 000564	
4. DATE OF RESUME 01 04 65	5. KIND OF RESUME D Change	6. SECURITY U RPT U WRK	7. REGRADING N/A
8. RELEASE LIMITATION NL	9. LEVEL OF RESUME A. Work Unit		

10a. CURRENT NUMBER/CODE 129-01-07-01-55

10b. PRIOR NUMBER/CODE

11. TITLE: Plasma Diagnostics

12. SCIENTIFIC OR TECH. AREA 006400 Fluid Mech., 013000 Plasma Physics, 009600 Masers & Lasers

13. START DATE 07-61

14. CRIT. COMPL. DATE N/A

15. FUNDING AGENCY NR OTHER

16. PROCURE. METHOD C. In-House

17. CONTRACT/GRANT N/A a. DATE b. NUMBER c. TYPE d. AMOUNT

18. RESOURCES EST.	a. PROFESSIONAL MAN-YEARS	b. FUNDS (In thousands)
PRIOR FY—65	0.6	119
CURRENT FY—66	1.4	155

19. GOVT. LAB/INSTALLATION/ACTIVITY

NAME: Jet Propulsion Laboratory

ADDRESS: 4800 Oak Grove Drive
Pasadena, California 91103

RESP. INDIV.: D. R. Bartz/G. R. Russell

TEL: 213-354-4060

20. PERFORMING ORGANIZATION N/A

NAME:

ADDRESS:

INVESTIGATORS PRINCIPAL:

ASSOCIATE:

TEL: TYPE:

21. TECHNOLOGY UTILIZATION

22. COORDINATION

23. KEYWORDS

24. Objectives: The long range objective is to develop the capability of measuring independently all the thermodynamic, radiative, and kinematic variables of a partially ionized gas which is not necessarily in equilibrium.

In FY 66, measurements of the electron density and plasma velocity will be emphasized utilizing several independent techniques.

25. Approach: Thomson scattering in a laser beam, Langmuir probes, and 90 and 24 G cps microwave systems will be used to measure electron densities. Spectroscopic methods utilizing lasers will be employed to measure the plasma velocity. Work with the magnetic velocity probe will be continued in a shock tube and compared with existing work utilizing steady-state plasmas. Spectroscopic work (relative line intensity measurements) will be continued to measure electron temperatures in nonequilibrium plasmas.

26. Progress: Both fixed and swinging-arm 24 G cps microwave systems have been completed and are currently being used on a routine basis. Langmuir probes are being used to measure both electron temperature and density. Electron temperatures have been measured using relative line intensity methods. Translating probes have been used to measure the plasma velocity and total pressure.

Kelly, A., "A Microwave Probe for Plasma Plumes," AIAA, March 1965.

Kelly, A., Gardner, J., Nerheim, N., "Electron Density and Temperature Measurements in the Exhaust of an MPD Arc, " paper to be given at summer meeting of AIAA. (July, 1965.)

27.	28. REQUESTING AGENCY	29. INTER-CENTER SUPPORT	30. CROSS CODE

31. SPECIAL EQUIPMENT

32. FUNDS ($ K)	IN-HOUSE	CONTRACT
PRIOR FY—65	119	N/A
CURRENT FY—66	155	N/A
NEXT FY—		

33. UNIQUE PROJECT Research Program, SRT

34. SUB PROGRAM Fluid Physics Research

35. TASK AREA Plasma Diagnostics

NASA FORM 1122 (AUGUST 64)
(Items 1 to 26 identical to DD Form 1498)

(OVER)

97

CONTINUATION SHEET

Description of FY66 Work Unit Objectives, Approach and Progress

129-01-07-01-55
PLASMA DIAGNOSTICS
D. R. Bartz, G. R. Russell

Objectives

The overall objective is to develop the capability of measuring independently all the thermodynamic, radiative, and kinematic variables of a partially ionized gas which is not necessarily in equilibrium.

In FY66 measurements of the electron density and plasma velocity will be emphasized utilizing several independent techniques.

Approach

The electron density will be measured utilizing three techniques - laser scattering, microwave diagnostics and Langmuir probes.

A giant pulsed laser is currently being assembled during FY65 to be used to measure electron densities by monitoring Thomson scattering from the beam in a partially ionized gas. The scattering experiments will first be conducted utilizing a stabilized stationary arc. If this proves successful, the Thomson scattering will be measured to determine the electron density gradients in and adjacent to a shock front.

The use of the 24 G cps system will be continued in FY66. The 90 G cps stationary and swinging arm systems will be assembled, tested, and should be available for routine use by the end of FY66.

Square-wave heating of Langmuir probes is being investigated in FY65, and will be continued in FY66. In particular, shock tube tests of the heated probes will be compared to steady-state tests conducted in the plasma vacuum facility utilizing a steady plasma source.

The plasma velocity will be measured with two techniques - the magnetic velocity probe, spectroscopic methods utilizing lasers. Work with the magnetic velocity probe will be continued in a shock tube during FY66 and compared to existing work utilizing steady-state plasmas. The doppler shift of the light from a laser beam directed almost parallel to the plasma flow will be used to measure the plasma velocity. These laser measurements will be compared with the magnetic velocity probe data.

Progress

Both fixed and swinging-arm 24 G cps microwave systems have been completed and are currently being used on a routine basis. Langmuir probes are being used to measure both electron temperature and density in the exhausts of the cross-field accelerator and MPD arcs.

The Langmuir probe data taken in the exhaust of the MPD arc has been compared with spectroscopic measurements of the electron temperature and microwave measurements of the electron density. The different methods agree quite closely except in regions of large plasma gradients. It is not yet clear (in these gradient regions) which of the diagnostic methods is the most reliable.

Papers published during FY65 in areas of Plasma Diagnostics are:

Kelly, A., "A Microwave Probe for Plasma Plumes," AIAA Journal, Vol. 3, No. 2, February 1965.

Kelly, A., Gardner, J., Nerheim, N., "Electron Density and Temperature Measurements in the Exhaust of a MPD Arc," AIAA Paper No. 65-298, presented at AIAA Second Annual Meeting, San Francisco, Calif. July 1965, accepted for AIAA Journal.

JPL Job No. 329-11401-1-3832
3-9-65

PLASMA DIAGNOSTICS
NASA Work Unit 129-01-07-01
JPL 329-11401-1-3832

LASERS

A giant-pulsed 100 Mw laser has been purchased and preliminary experiments have begun to determine the feasibility of using the laser to measure both the plasma electron density and velocity. The velocity will be measured using two techniques: measurement of the doppler shift of the laser radiation (because of the plasma motion), and by producing a local electrical breakdown in the plasma using a focused laser beam and later time-of-flight measurements of the ionized plasma element produced by the initial breakdown. The latter of these techniques is being tried first. Breakdown in a cold gas (argon at 300°K) has been achieved in a focused laser beam of 50 Mw. The magnitude of the diffusion of the plasma formed in the breakdown is now being investigated and, on completion of the diffusion experiments, velocity measurements in both cold gas and plasmas will be made in supersonic jets at ambient pressures of from 10^2 to $10^3 \mu$ in a vacuum tank. These experiments will be concluded in the first half of FY 1966. In the second quarter of FY 1966, the laser diagnostics using doppler shift will be started. Both laser techniques will be compared with the magnetic velocity probe.

Electron densities will be measured by monitoring Thomson scattering perpendicular to a laser beam in a partially ionized gas. The scattering experiment will first be conducted with a stabilized stationary arc in a discharge tube. If the preliminary scattering experiment in the discharge tube proves to be successful, the technique will be used to measure electron density gradients in and adjacent to a shock front in a partially ionized gas.

MAGNETIC VELOCITY PROBE

The shock tube study has been delayed approximately 6 mo because of a delay in the delivery of a test section to the Aerodynamics Facilities Section at JPL. Preliminary experiments with the shock tube (operated by the Aerodynamics Facilities Section) will be started in the first quarter of FY 1966. The effects of square wave heating of the probe elements, magnetic field configurations, and probe geometry will be emphasized and the results will be compared with steady-state tests conducted in a plasma vacuum facility using a steady plasma source.

MICROWAVE DIAGNOSTICS

Extensive measurements in the plume of a MPD source have been made with the 24 gc swinging arm (Ref. 1), measuring both transmission and reflection. The results are summarized in Ref. 2. The capability of the 24 gc system (both fixed and swinging arm) has been extended to include the measurement of phase as well as transmission and reflection, thereby extending the electron density measurements to $7 \times 10^{11} \lesssim n_e \lesssim 7 \times 10^{13}$. All the components needed for the 90 gc system have been received, and assembly of the first fixed geometry system will begin in the first quarter of FY 1966.

LANGMUIR PROBES

Langmuir probes have been used to measure electron densities and temperatures in the plume of a MPD source. A technique has been worked out to eliminate the uncertainty because hot electrical insulators (in this case boron nitride) can act as additional collectors of current. The technique and experimental results are reported in Ref. 2. Probe measurements are still limited to flows where the probe can be cooled enough to prevent appreciable emission from occurring at the probe tip. In the first half of FY 1966, square wave heating of Langmuir probes will be initiated and measurements will be extended to higher pressures (where a departure from the simple Langmuir theory is to be expected). Data obtained from these high pressure experiments will be compared to microwave data, which should not be sensitive to the increase in pressure.

SPECTROSCOPIC DIAGNOSTICS

Spectroscopic measurements of the intensities of 12 argon II lines made with a Jarrel-Ash 0.5 m Ebert monochrometer were used to determine the electron temperature in a MPD plume by the relative line intensity method. Both direct and Abel inversion techniques were used to obtain average electron temperatures in the plume, and temperature profiles across the plume diameter. The results are reported in Ref. 2. Measurements of plasma electron temperatures produced by a number of different plasma sources will be conducted in FY 1966.

MASS SPECTROMETER

The measurement of electron recombination rates will be continued in FY 1966. At low electron temperatures, the dissociative recombination rate may be the dominant recombination mechanism. Because it is believed that this rate is controlled by the rate of production of molecular ions, the molecular ion production rate will be measured with the use of a mass spectrometer. The mass spectrometer has been purchased and delivery will be made in the first quarter of FY 1966. Measurements using the spectrometer will be started at the end of the first half of FY 1966.

PRESENTATIONS

Two papers titled, "Diagnostics Studies of an MPD Arc," by N. Nerheim and "Microwave Diagnostics," by A. Kelly were presented before the NASA Research Advisory Committee on Fluid Mechanics at JPL on May 6, 1965.

REFERENCES

1. Kelly, A. J., A Microwave Probe for Plasma Plumes, AIAA, 3, 372, 1965.

2. Kelly, A. J., Nerheim, N. M., Gardner, J. A., Electron Density and Temperature Measurements in the Exhaust of a MPD Source, AIAA Second Annual Meeting and Technical Demonstration, San Francisco, California, July 26-29, 1965.

ELECTRO PHYSICS - DIVISION 34

TITLE NASA Code JPL Code	FISCAL YEAR	PROFESSIONAL MAN-YEARS	DOLLARS (in 000's)
Thermionics Research			
129-02-01-07 329-21101-1-3450	1964 1965 1966	1.0 1.5 2.0	90 140 152
Optical Physics Research			
129-02-05-01 329-20101-1-3450	1964 1965 1966	4.6 3.0 3.0	306 210 203
Cryogenics Research			
129-02-05-02 329-20201-1-3450	1964 1965 1966	1.7 2.0 2.0	201 200 163
Magnetics and Thermoelectrics Research			
129-02-05-06	1964 1965 1966	1.6 1.5 2.0	197 205 142
Semiconductor Research			
129-02-05-09	1965 1966	0.8 2.0	80 156

329-20101-1-3450

RESEARCH AND TECHNOLOGY RESUME

1.	2. GOVT. ACCESSION	3. AGENCY ACCESSION NR 000576
4. DATE OF RESUME: 01 04 65	5. KIND OF RESUME: D CHANGE	6. SECURITY: U U
7. REGRADING: N/A	8. RELEASE LIMITATION: NL	9. LEVEL OF RESUME: A. Work Unit
10a. CURRENT NUMBER/CODE: 129-02-05-01-55	10b. PRIOR NUMBER/CODE: (NONE)	

11. TITLE: U OPTICAL PHYSICS RESEARCH

12. SCIENTIFIC OR TECH. AREA: SOLID STATE 015700; OPTICS 012000; NAVIGATION & GUIDANCE 010800

13. START DATE: 01 62 | 14. CRIT. COMPL. DATE: N/A | 15. FUNDING AGENCY: NR OTHER

16. PROCURE. METHOD: C IN-HOUSE

17. CONTRACT/GRANT: N/A — a. DATE — b. NUMBER — c. TYPE — d. AMOUNT

18. RESOURCES EST.	a. PROFESSIONAL MAN-YEARS	b. FUNDS (In thousands)
PRIOR FY-65	3.0	210
CURRENT FY-66	3.0	175

19. GOVT. LAB/INSTALLATION/ACTIVITY
NAME: Jet Propulsion Laboratory
ADDRESS: 4800 Oak Grove Drive
Pasadena, California 91103
RESP. INDIV. N. Sirri/A. R. Johnston
TEL. 213-354-4410

20. PERFORMING ORGANIZATION
NAME:
ADDRESS: (Same as 19)
INVESTIGATORS PRINCIPAL:
ASSOCIATE
TEL: TYPE:

21 TECHNOLOGY UTILIZATION

22. COORDINATION

23 KEYWORDS

24 Objectives. To conduct research on the interaction of light with matter, which will lead to a better understanding of the basic operation of optical sensors. Three immediate objectives are: (1) to obtain a better understanding of the electro-optic effect in ferroelectric crystals such as $BaTiO_3$; (2) to obtain a better understanding of optical frequency doubling in the reflection of ruby laser light from these same crystals; and (3) to obtain a better understanding of photoconductive detectors such as CdS.

Approach. (1) The measurements of the low-frequency electro-optic effect in $BaTiO_3$ are being supplemented by transient measurements which closely approach the strain-free condition. The response is smaller, roughly in proportion to the decrease found in the dielectric constant from the low-frequency value to the strain-free value. Interpretation should clarify the role of strain in the electro-optic effect. (2) The second-order polarization constants are measured by determination of the amount of second-harmonic light that is produced at a surface of a crystal as a function of orientation of the crystal and light polarization, when the incident light is impinging at a 45° angle of incidence. (3) Effects of temperature and previous history of light exposure on photoconductive detectors will be investigated. Hopefully, a model will be obtained for predicting the resistance change for a given light input under given conditions.

Progress. (1) M. S. Shumate, "Interferometric Determination of the Principal Refractive Indices of $BaTiO_3$ Single Crystals," Appl. Phys. Lett. 5, 178 (Nov. 19, 1964); (2) A. R. Johnston, "Determination of the Low-Frequency Linear Electro-Optic Effect in Tetragonal $BaTiO_3$," (submitted to J. Opt. Soc. Am.); (3) A. R. Johnston, "Strain-Free Electro-Optic Effect in $BaTiO_3$," APS Meeting, Apr. 26, 1965, Wash., D.C.; (4) J. M. Weingart and A. R. Johnston, "Electronic Polarimeter Techniques," Proc. of Symposium on the Ellipsometer & Its Uses, Wash., D.C., 1963, ed. E. Passaglia; (5) JPL SPS 37-27, 30, 31, all in Vol. IV.

27. | 28. REQUESTING AGENCY | 29. INTER-CENTER SUPPORT: N/A | 30. CROSS CODE

31. SPECIAL EQUIPMENT

32. FUNDS ($ K)	IN-HOUSE	CONTRACT
PRIOR FY-65	210	N/A
CURRENT FY-66	175	N/A
NEXT FY—		

33. UNIQUE PROJECT: Research Program (129)
34. SUB PROGRAM: Electro Physics Research (02)
35. TASK AREA: Physics of Solids (05)

NASA FORM 1122 (AUGUST 64) (Items 1 to 26 identical to DD Form 1498) (OVER)

OPTICAL PHYSICS RESEARCH
NASA Work Unit 129-02-05-01
JPL 329-20101-1-3450

ELECTRO-OPTIC EFFECT

The investigation of the electro-optic effect in single crystal $BaTiO_3$ during the last 6 mo has been concentrated on measurements under the condition of constant strain. The low frequency results are complete, and have been reported in the Journal of the Optical Society of America (Ref. 1). The method for making the strain-free measurements through observation of the transient response of a single-crystal sample to an applied field in the form of a step function is now developed to a point of reasonable convenience and accuracy. The applicable response time of our fastest photomultipliers is approximately 5 nanoseconds, while all other components of the apparatus are capable of one order of magnitude faster responses. The 5-nanosecond response is fast enough to satisfy the strain-free requirements, but remains as the single predominant factor limiting overall response time.

The measurement has now been made on three crystal samples for each configuration, thus avoiding error from domain structure and sample-to-sample variation. An [001] field is used to measure $r'_{33} - r'_{13}$, and a [100] field, for measuring r'_{42}. The primes are used to designate values of the electro-optic coefficients under the strain-free condition. Here, r_{ij} is defined by

$$\Delta(1/n_i)^2 = \sum_{j=i}^{3} r_{ij} E_j ,$$

where

n is the index of refraction

E is the applied field, and the conventional contracted subscripts are used.

Strain-free dielectric constants were measured on crystals from the same lot by a similar transient method. Empirically, the optical response per unit induced polarization, $r/(\epsilon - \epsilon_o)$, is a useful quantity, being nearly constant with temperature, and even of similar magnitude (within about a factor of two) for different materials (Ref. 2). Here, ϵ is the appropriate dielectric constant for the configuration used, and ϵ_o is the dielectric constant of a vacuum. Our results show that $BaTiO_3$ fits this concept fairly well, except that for a low-frequency [001] field, the quantity $(r_{33} - r_{13})/(\epsilon_c - \epsilon_o)$ decreases with rising temperature, and is significantly smaller under strain-free conditions.

Analogous measurements of the quadratic (Kerr) effect above the Curie transition at 120°C were made, with the unexpected result that there is a large (60%) strain contribution even in the cubic state. There can be no piezoelectric strain in cubic $BaTiO_3$, so our present interpretation is that the electrostrictive strain (proportional to E^2) is responsible for the observed clamping effect. Previous discussions in the literature, for example, have assumed that no clamping is possible in a centrosymmetric crystal structure (Ref. 3).

A paper describing these results has been prepared and has been submitted to Applied Physics Letters. A more general paper on the applications of the electro-optic effect, and the influence of the strain-optical coupling has been accepted for presentation at the AGARD symposium on Opto-Electronic Components and Devices, in Paris, in September 1965. Also, a detailed paper on the technique of measuring rapidly changing birefringence is planned for the Journal of Applied Optics.

Further work will include interpretation of the experimental results for $BaTiO_3$ to provide a useful model to explain them.

Also, it is important to extend the same kind of measurement to other crystals, and efforts will be made to obtain a variety of suitable crystal samples.

References

1. Johnston, A. R., and Weingart, J. M., J. Opt. Soc. Am., Vol. 55, XXX (1965) (July issue).

2. Miller, Robert C., Appl. Phys. Lett., Vol. 5, 17 (1964).

3. Geusic, J. E., Kurtz, S. K., Van Uitert, L. G., and Wemple, S. L., Appl. Phys, Lett., Vol. 4, 141 (1964).

OPTICAL SECOND ORDER POLARIZATION COEFFICIENTS

The experimental phase of the determination of the optical second order polarization coefficients of barium titanate is essentially complete.

Ample data to determine the three coefficients, d_{13}, d_{33}, and d_{42} as a function of temperature has been recorded, and all that remains is to perform a calibration check of the phototubes used.

Because the measurement was performed in reflection from a surface at an angle of incidence different from zero, there is some possibility that the surface itself will contribute some second harmonic independent of that which is generated on the surface layer of the crystal. Because of lack of time, however, it was not possible to investigate this experimentally. Indications are that the surface contribution is probably small.

Future work will include completion of the data reduction on the recently completed temperature runs, interpretation of results, and preparation of a final report. A paper will also be presented at the fall meeting of the American Optical Society.

Present plans are to select a new project and to initiate work on it during the next 6-mo period.

STRUCTURE AND PHOTO-CONDUCTIVE PROPERTIES OF EVAPORATED CADMIUM SULFIDE FILMS

This work was started on April 30, 1965, on which date the principal scientist arrived from Japan as a resident research appointee at JPL. A brief description of the present investigation is as follows:

1. General

Cadmium sulfide thin films evaporated in a vacuum may be used as photoconductive sensors and as dielectrics in electronic devices. The object of this research is to study the relationship between the structure and photoconductive properties of these thin films. The following will be checked as functions of the evaporation rate, the temperature of the source and the substrate, sticking probability of the vapor molecules to the substrate, and also the surface condition and material of the substrate:

1. The composition of the cadmium sulfide vapor in its molecular beam.
2. The crystal, textural, and defect structures of the cadmium sulfide films.
3. The effects of impurities.
4. Photoconductivity.

2. Experimental procedures

a. Vapor analysis. The composition of cadmium sulfide vapor evaporated from a source will be analyzed by using a mass-spectrometer.

b. Structure analysis. The structure of the film will be checked by X-ray and electron diffraction methods, the surface state by electron-microscopy, and the composition by fluorescent X-ray analysis.

c. Measurements on resistivity and photoconductivity. The resistivity, Hall coefficient, and mobility of electrons will be measured as a function of light intensity by using ohmic contact electrodes.

3. Test apparatus.

The following test apparatus will be used:

1. Vacuum unit (VEECO, VE-400).
2. Quadrupole residual gas analyzer (Varian, Model 980-120).

3. Quartz crystal balance (Westinghouse, Model 701).

4. Quartz crucible or oven to produce the molecular beam of cadmium sulfide.

PUBLICATIONS

1. Johnston, A. R., and Weingart, J. M., "Determination of the Low-Frequency Linear Electro-Optic Effect in Tetragonal $BaTiO_3$," J. Opt. Soc. Am., Vol. 55, XXX (July 1965).

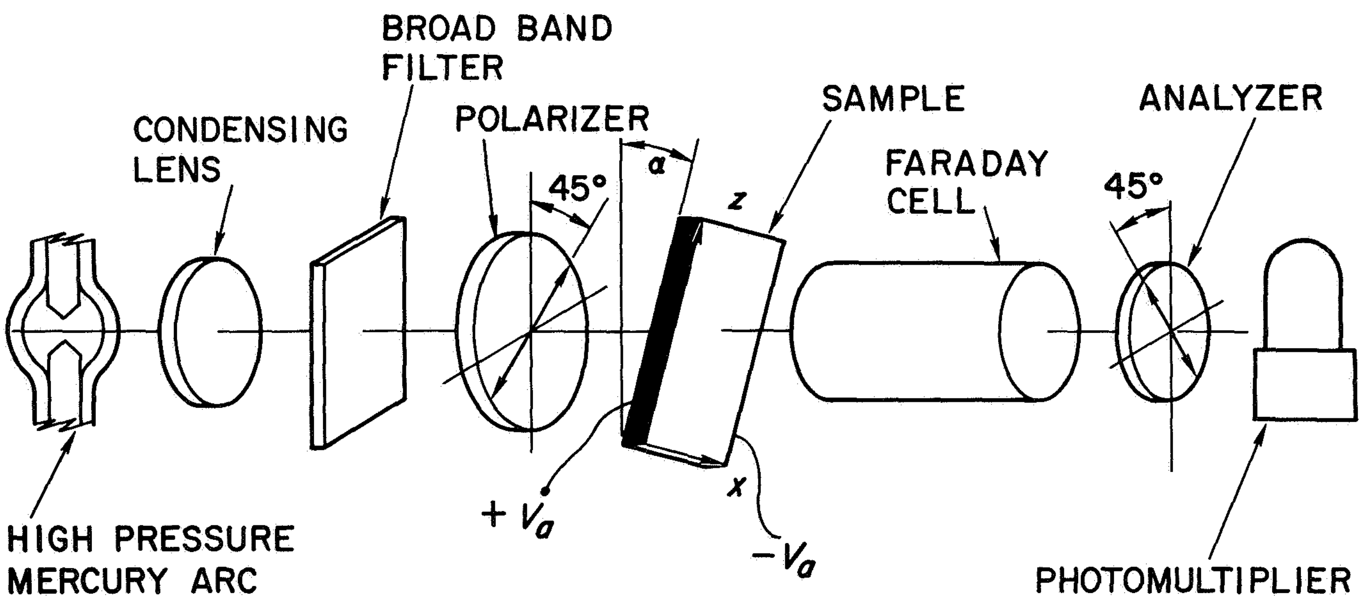
2. Johnston, A. R., "Linear Electro-Optic Effect in Tetragonal $BaTiO_3$," Bull. Am. Phys. Soc., Vol. 10, 473 (1965).

3. Johnston, A. R., Electro-Optic Crystals and Their Use for Light Modulation, to be presented at the Ninth Technical Meeting of the AGARD Avionics Panel, September 6-9, 1965, Paris, France.

4. Johnston, A. R., "The Strain-Free Electro-Optic Effect in Single-Crystal Barium Titanate," submitted to Applied Physics Letters.

5. Shumate, M. S., Theory of Optical Harmonic Generation in Barium Titanate, p. 93, JPL Space Programs Summary 37-31, Vol. IV.

6. Shumate, M. S., "Interferometric Measurement of Large Indices of Refraction," submitted to the Journal of Applied Optics.



BROAD BAND
FILTER
CONDENSING
LENS
POLARIZER
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SAMPLE
FARADAY
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ANALYZER
45°
HIGH PRESSURE
MERCURY ARC
+ V_a
x
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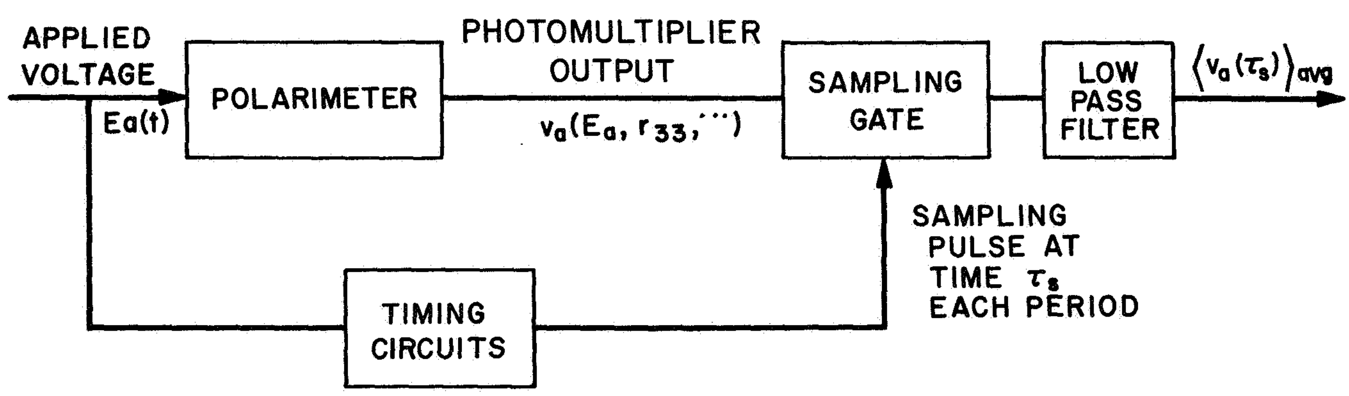
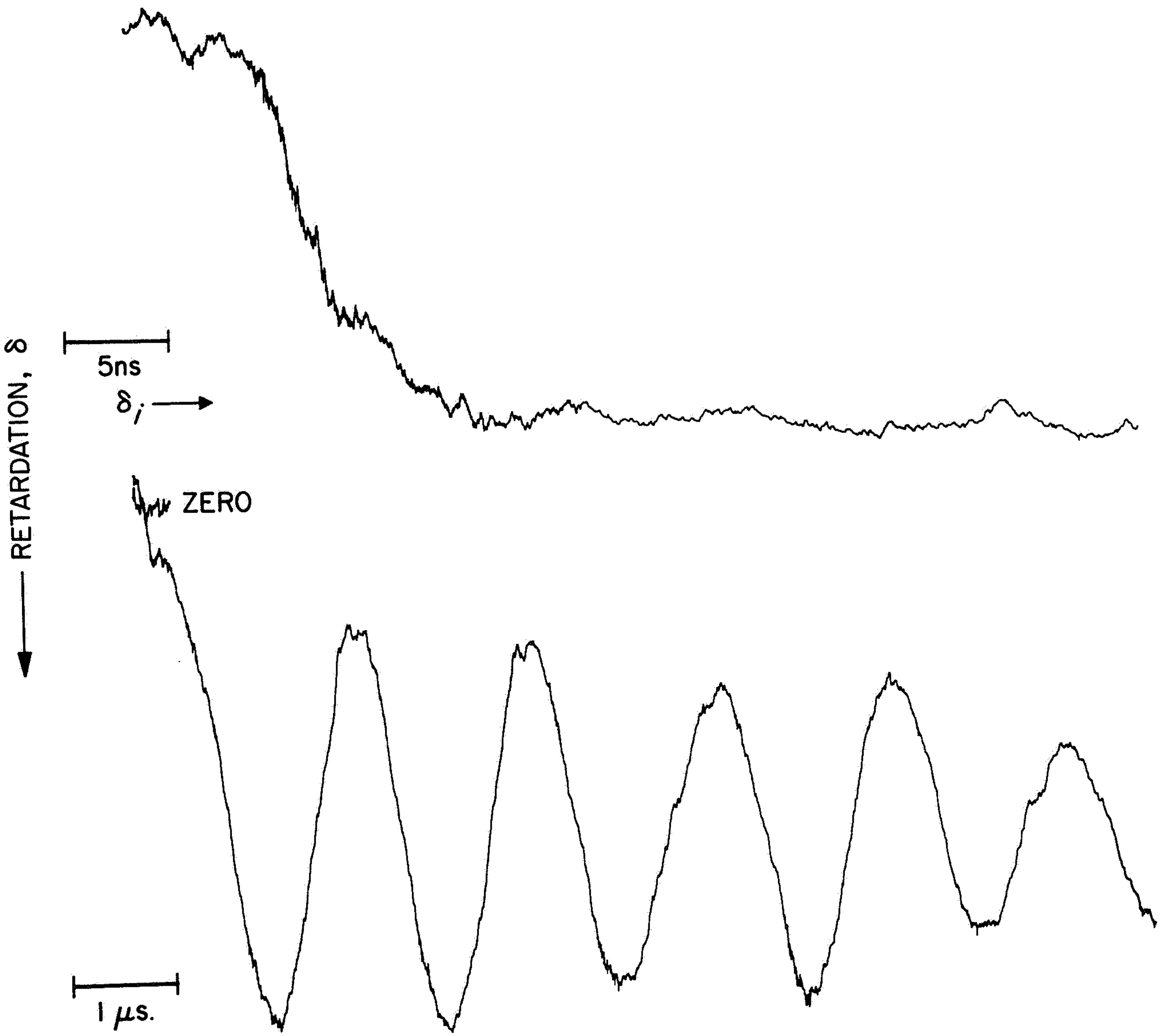
PHOTOMULTIPLIER


APPLIED VOLTAGE
Ea(t)
POLARIMETER
PHOTOMULTIPLIER OUTPUT
va(Ea, r33, ...)
SAMPLING GATE
LOW PASS FILTER
⟨va(τs)⟩avg
SAMPLING PULSE AT TIME τs EACH PERIOD
TIMING CIRCUITS



RETARDATION, δ
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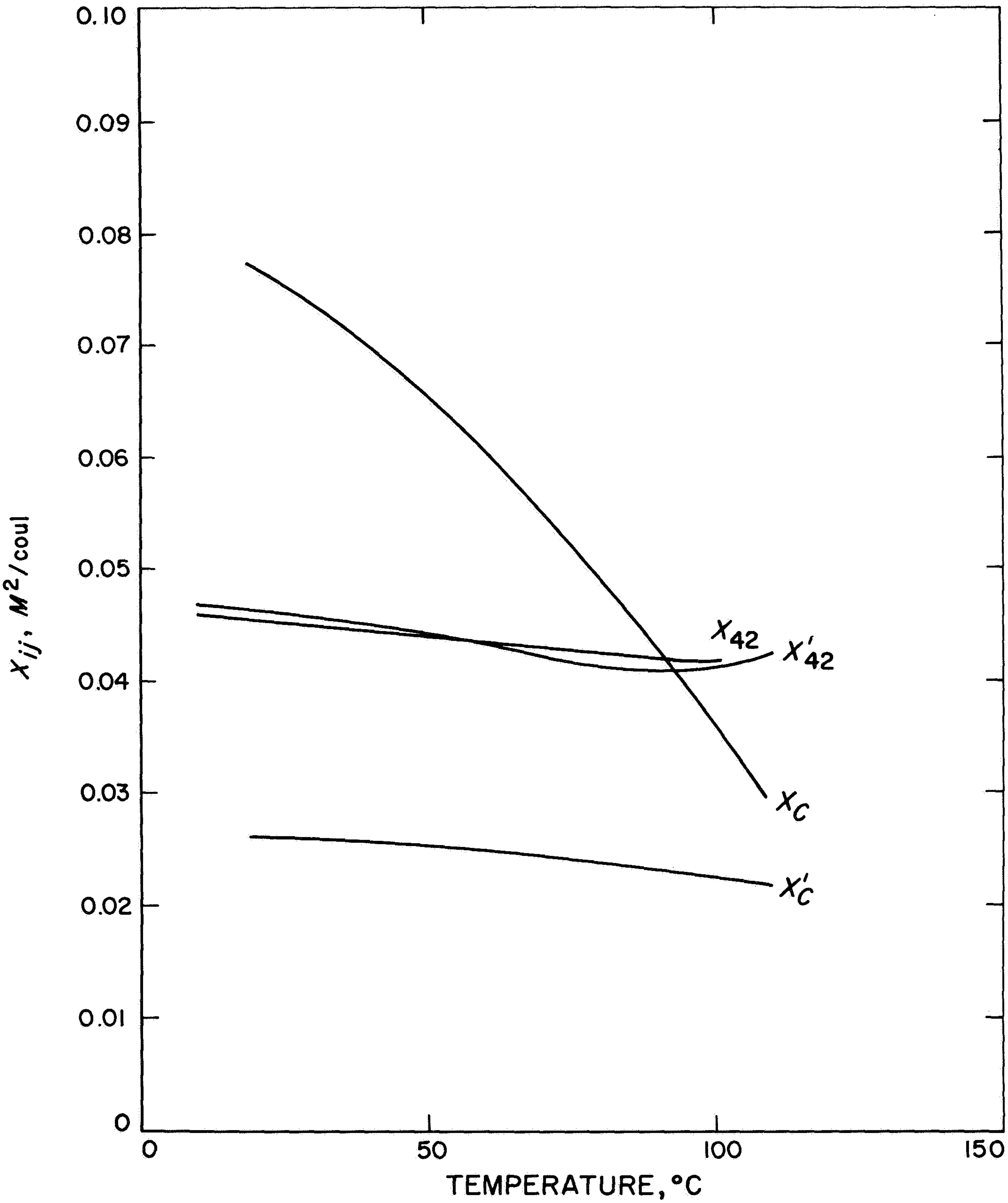

0.10
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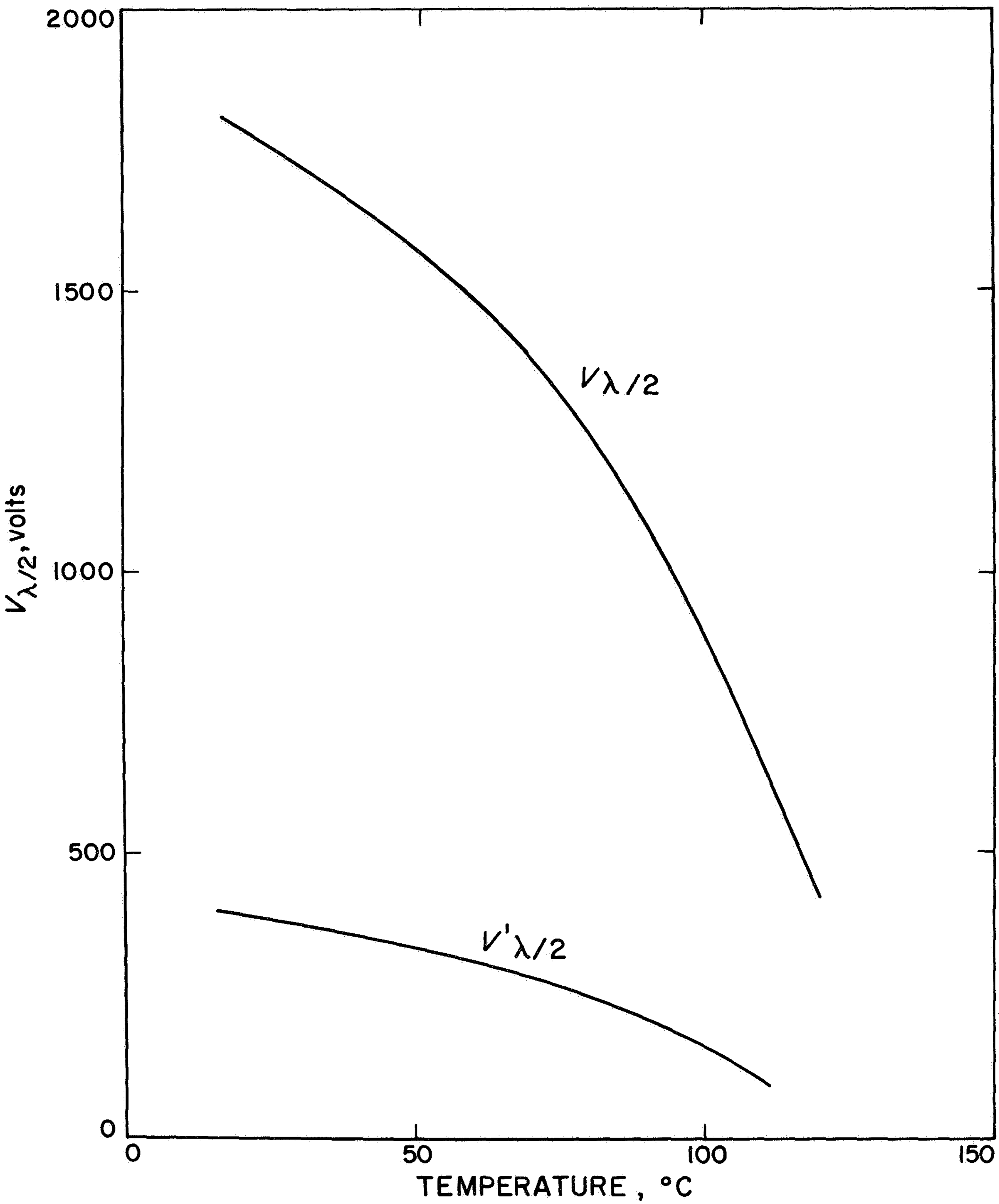
0.02
0.01
0
0
50
100
150
TEMPERATURE, °C
X_{ij}, M^2/coul
X_{42}
X'_{42}
X_C
X'_C

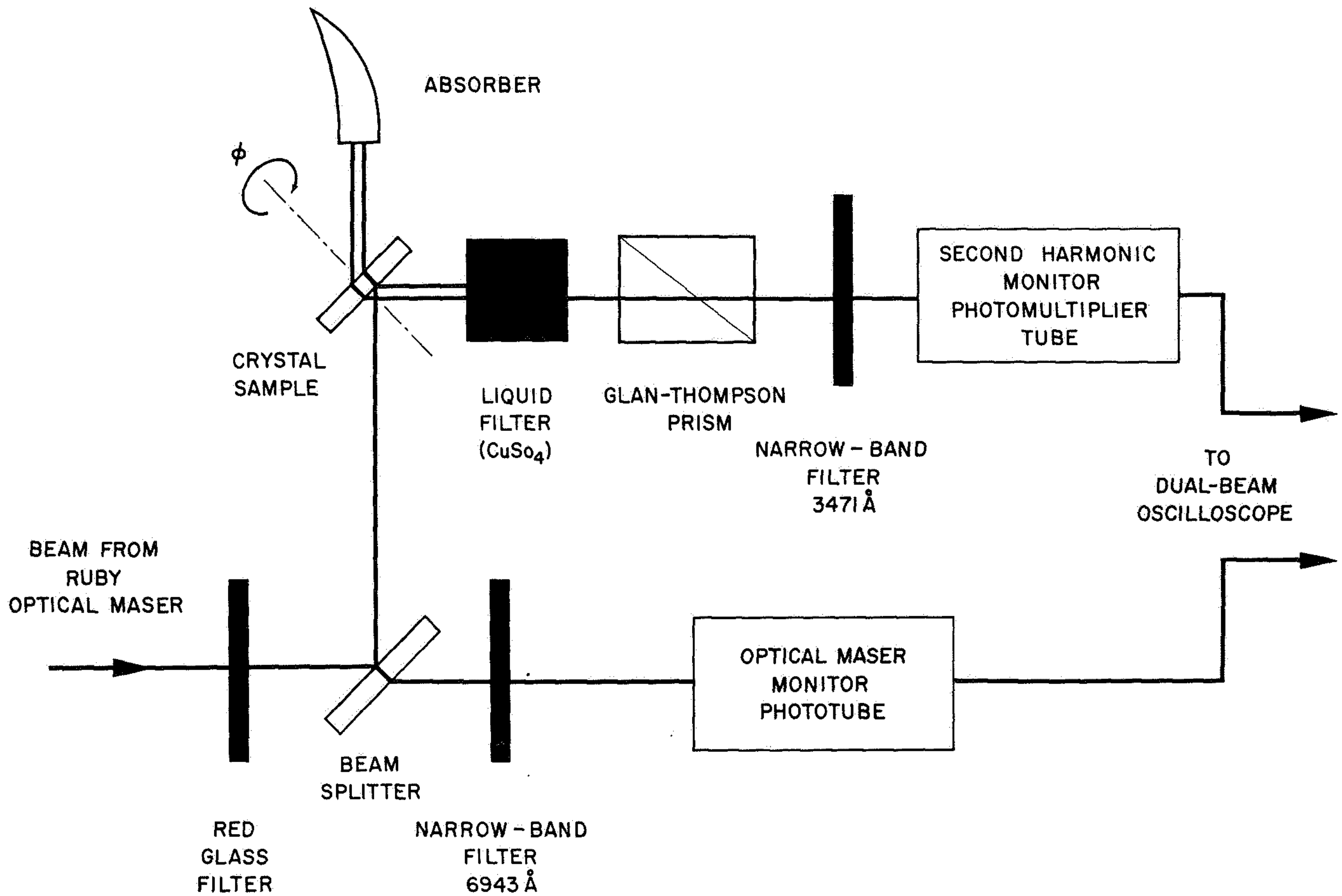


2000
1500
1000
500
0
$V_{\lambda/2}$, volts
0
50
100
150
TEMPERATURE, °C
$V\lambda/2$
$V'\lambda/2$

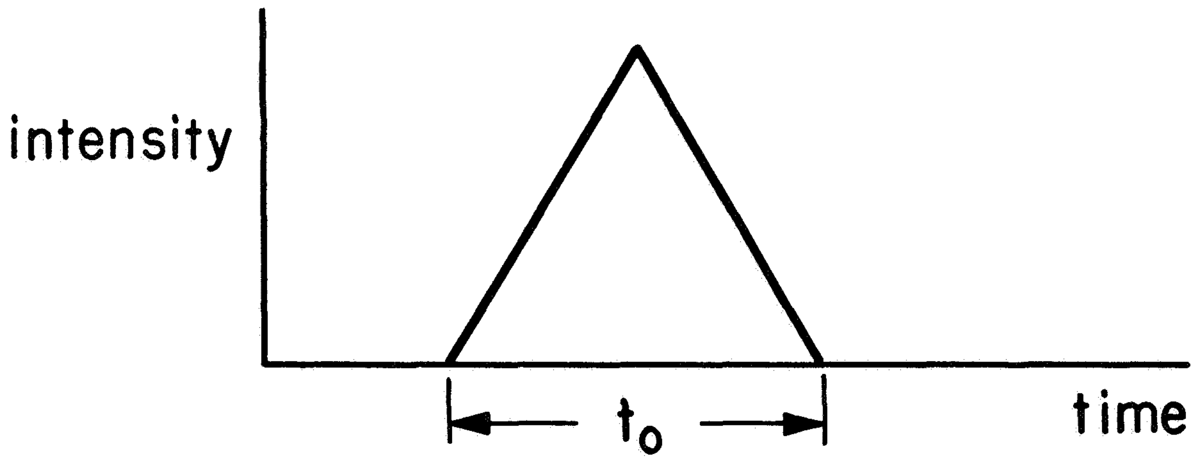
$$P_i = \chi_{ij} E_j + d_{ilm} E_l E_m + \dots$$

$$E_\perp^r (2\omega) = k_\perp \left[(d_{15} + d_{31}) \sin\phi \cos^2\phi + d_{33} \sin^3\phi \right] \left[E_\perp^s (\omega) \right]^2$$

$$E_{\parallel}^r (2\omega) = k_{\parallel} \left[(d_{33} - d_{15}) \sin^2\phi \cos\phi + d_{31} \cos^3\phi \right] \left[E_\perp^s (\omega) \right]^2$$


ABSORBER
ϕ
CRYSTAL SAMPLE
LIQUID FILTER ($CuSo_4$)
GLAN-THOMPSON PRISM
NARROW-BAND FILTER 3471 Å
SECOND HARMONIC MONITOR PHOTOMULTIPLIER TUBE
TO DUAL-BEAM OSCILLOSCOPE
BEAM FROM RUBY OPTICAL MASER
RED GLASS FILTER
BEAM SPLITTER
NARROW-BAND FILTER 6943 Å
OPTICAL MASER MONITOR PHOTOTUBE

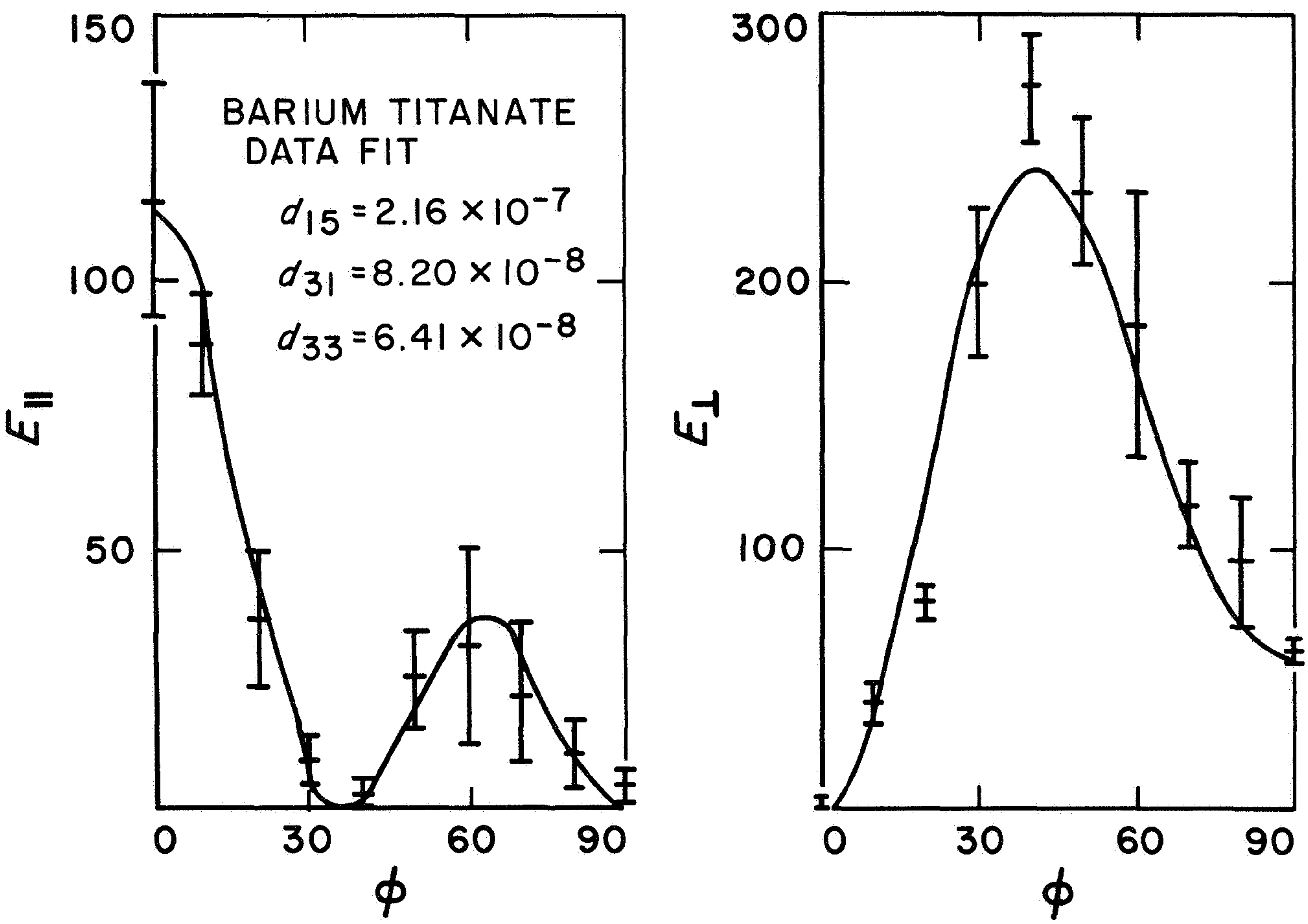
$$\pi(2\omega) = \alpha\,\pi^2(\omega)$$



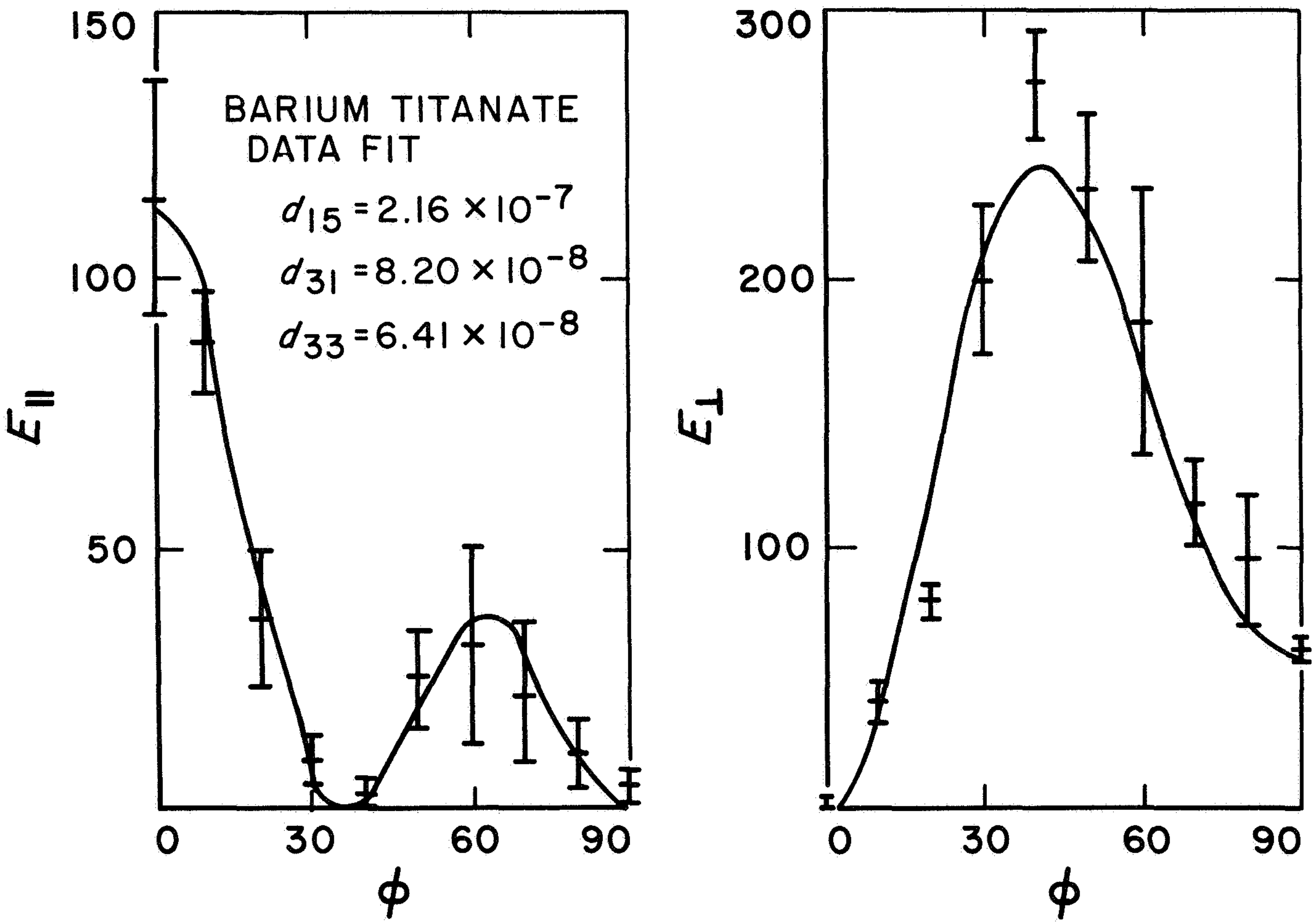
$$W\left(\begin{matrix}\omega\\ 2\omega\end{matrix}\right) = \int_{\substack{\text{one}\\ \text{shot}}} \Pi\left(\begin{matrix}\omega\\ 2\omega\end{matrix}\right) dt$$

$$W(2\omega) = \frac{8}{3}\,\frac{\alpha}{n t_0}\,W^2(\omega)$$

n = average number of pulses per shot



BARIUM TITANATE
DATA FIT
$d_{15} = 2.16 \times 10^{-7}$
$d_{31} = 8.20 \times 10^{-8}$
$d_{33} = 6.41 \times 10^{-8}$
$E_{\parallel}$
$E_{\perp}$
ϕ
150
100
50
300
200
100
0
30
60
90


BARIUM TITANATE
DATA FIT
$d_{15} = 2.16 \times 10^{-7}$
$d_{31} = 8.20 \times 10^{-8}$
$d_{33} = 6.41 \times 10^{-8}$
$E_{\parallel}$
$E_{\perp}$
150
100
50
300
200
100
0
30
60
90
0
30
60
90
ϕ
ϕ

KDP RESULT

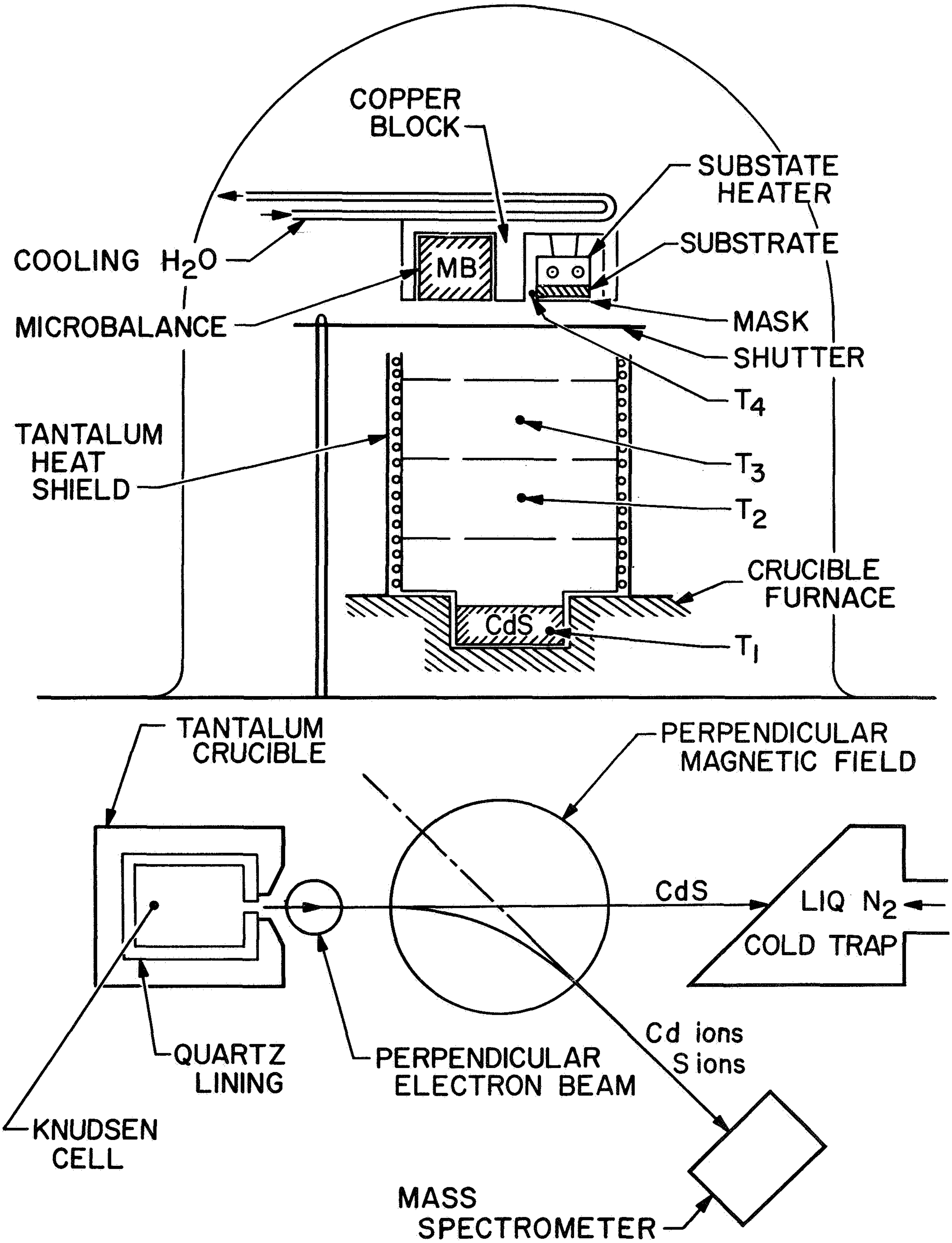
WAVELENGTH	d_{36}
0.6943μ	$2 \pm 2 \times 10$
1.15μ*	$3 \pm 1 \times 10^{-}$

* A. ASHKIN, G. D. BOYD, J. M. DZIEDZIC, PHYS. REV. LETTERS **11**, 14 (1963)

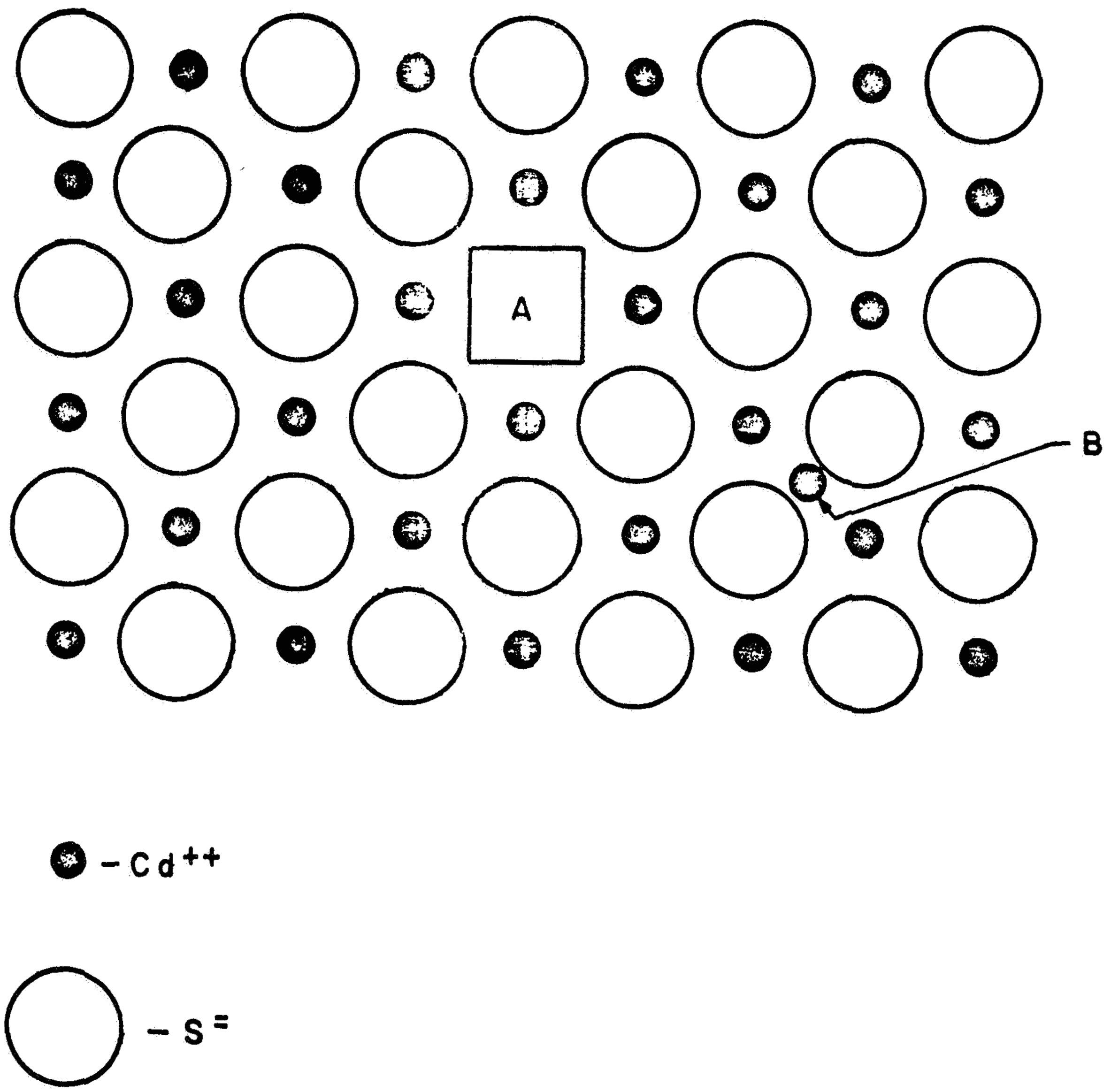
BARIUM TITANATE RESULTS

WAVELENGTH	d_{15}	d_{31}	d_{33}
$0.6943\,\mu$	$1.6 \pm 0.5 \times 10^{-7}$	$6.0 \pm 2 \times 10^{-8}$	$5.8 \pm 1 \times 10^{-8}$
$1.06\,\mu$*	$1.05 \pm 0.09 \times 10^{-7}$	$1.11 \pm 0.09 \times 10^{-7}$	$4.2 \pm 0.3 \times 10^{-8}$

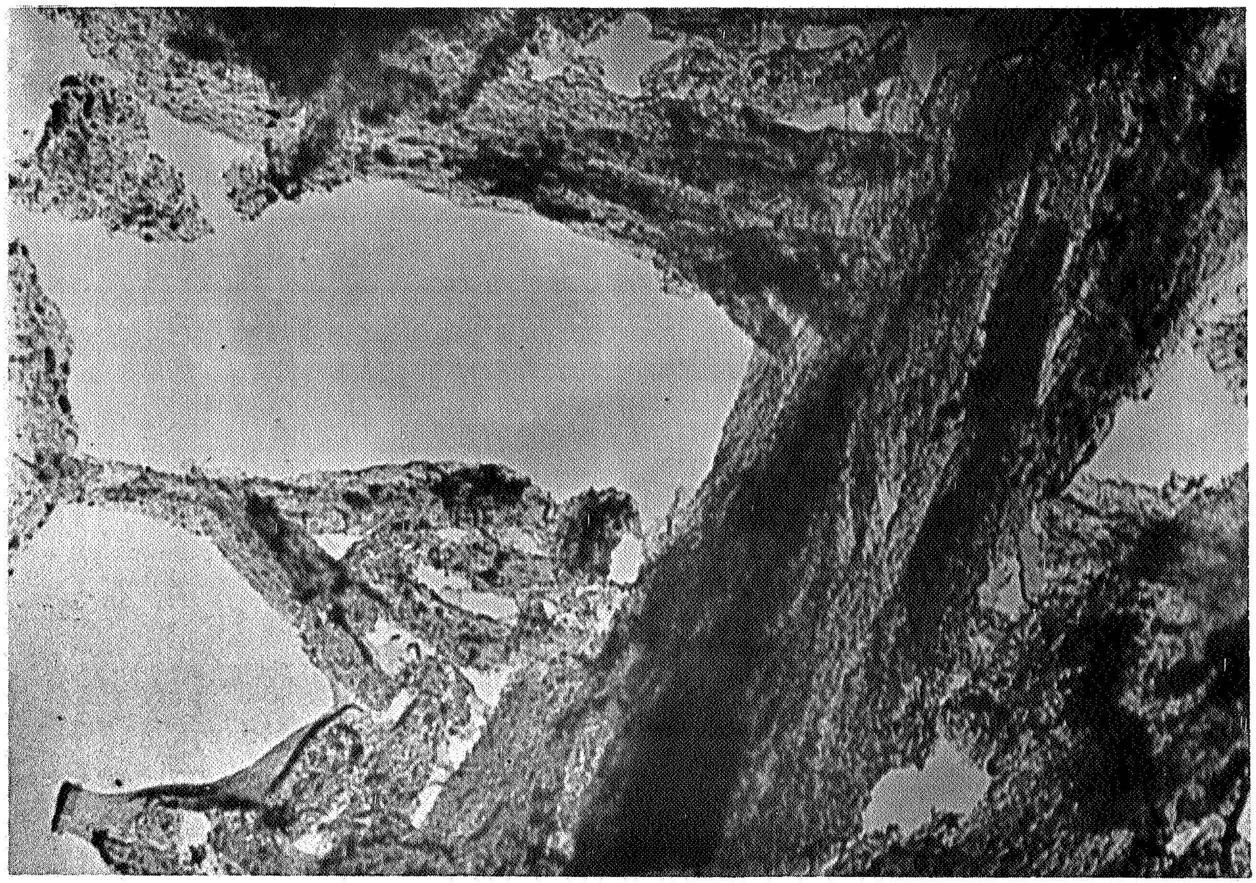
* R. C. MILLER, PHYS. REV. LETTERS 11, 146 (1963)



COPPER BLOCK
SUBSTATE HEATER
SUBSTRATE
COOLING H_2O
MB
MICROBALANCE
MASK
SHUTTER
T_4
TANTALUM HEAT SHIELD
T_3
T_2
CRUCIBLE FURNACE
CdS
T_1
TANTALUM CRUCIBLE
PERPENDICULAR MAGNETIC FIELD
CdS
LIQ N_2
COLD TRAP
Cd ions
S ions
QUARTZ LINING
PERPENDICULAR ELECTRON BEAM
KNUDSEN CELL
MASS SPECTROMETER



Schematic drawing of the CdS crystal structure showing (A) a sulfur ion vacancy and (B) a cadmium ion interstitial.



329-21101-1-3450

RESEARCH AND TECHNOLOGY RESUME	1.	2. GOVT ACCESSION	3. AGENCY ACCESSION NR 000570	
4. DATE OF RESUME 01 04 65	5. KIND OF RESUME D CHANGE	6. SECURITY U RPT U WRK	7. REGRADING N/A	8. RELEASE LIMITATION NL	9. LEVEL OF RESUME A. Work Unit

10a. CURRENT NUMBER/CODE 129-02-01-07-55	10b. PRIOR NUMBER/CODE (NONE)
11. TITLE: U THERMIONICS RESEARCH	

12. SCIENTIFIC OR TECH. AREA	13. START DATE	14. CRIT. COMPL. DATE	15. FUNDING AGENCY
PLASMA PHYSICS 013000 POWER SOURCES 013200	09 62	N/A	NR OTHER

16. PROCURE. METHOD	17. CONTRACT/GRANT	18. RESOURCES EST.	a. PROFESSIONAL MAN-YEARS	b. FUNDS (In thousands)
C IN-HOUSE	a. DATE N/A	PRIOR FY-65	1.5	140
	b. NUMBER c. TYPE d. AMOUNT	CURRENT FY-66	2.0	160

19. GOVT. LAB/INSTALLATION/ACTIVITY

NAME: Jet Propulsion Laboratory
ADDRESS: 4800 Oak Grove Drive
Pasadena, California 91103

RESP. INDIV.: N. Sirri/K. Shimada
TEL.: 213-354-4410

20. PERFORMING ORGANIZATION

NAME:
ADDRESS: (Same as 19)
INVESTIGATORS PRINCIPAL
ASSOCIATE
TEL: TYPE:

21. TECHNOLOGY UTILIZATION

22. COORDINATION

23. KEYWORDS

24 Objectives. To better understand the physics of cesium-thermionic diodes for the direct conversion of heat to electricity. Three immediate objectives are: (1) to explain the oscillations which occur in thermionic diodes, (2) to obtain and study low-frequency magnetosonic oscillations in a thermionic diode with an applied static magnetic field, and (3) to operate and study a cesium diode with a "hot plasma" emitter.

Approach. (1) & (2) Diodes of cylindrical geometry will be used in experiments to relate the oscillations occurring with and without the application of an external magnetic field. A proposed theory based upon space-charge instability in cesium thermionic diodes will be experimentally tested. Dynamic solutions for the instability problem will be sought. Generation of magnetosonic waves will be attempted with an external magnetic field applied. An attempt will be made to couple out energy at the frequency of the magnetosonic oscillations. To encompass wide operating conditions, glass diodes of various geometry and metal/ceramic diodes for operation at higher cesium pressures will be constructed. (3) A cesium plasma will be contained inside of a cup-shaped emitter with an external magnetic field. High-speed electrons will be extracted from a "ball-of-fire," formed in the cup, to flow in an external circuit.

Progress. (1) K. Shimada, "Oscillations in a Close-Gapped Thermionic Energy Converter," Report on the Thermionic Conversion Specialist Conference, Cleveland, O., Oct. 1964, pp. 181-187; (2) K. Shimada, "Low-Frequency Oscillations in Cylindrical Cesium Diodes," 25th Physical Electronics Conference, M.I.T., Cambridge, Mass., March 24-25, 1965; (3) G. I. Cohn, "Research Towards an AC Plasma Diode," JPL SPS 37-28, Vol. IV, 31-39; (4) K. Shimada, "Oscillations in a Close-Gapped Thermionic Energy Converter," JPL SPS 37-30, Vol. IV, 53-56; (5) G. I. Cohn, "Magnetosonic Waves," JPL SPS 37-30, Vol. IV, 56-64.

27.	28. REQUESTING AGENCY	29. INTER-CENTER SUPPORT	30. CROSS CODE
		N/A	

31. SPECIAL EQUIPMENT

32. FUNDS ($ K)	IN-HOUSE	CONTRACT
PRIOR FY-65	140	N/A
CURRENT FY-66	160	N/A
NEXT FY—		

33. UNIQUE PROJECT	Research Program, SRT	(129)
34. SUB PROGRAM	Electro Physics Research	(02)
35. TASK AREA	Physics of Ionized Gases	(01)

NASA FORM 1122 (AUGUST 64) (OVER)
(Items 1 to 26 identical to DD Form 1498)

ELECTRO PHYSICS RESEARCH (129-02)

THERMIONICS RESEARCH
NASA Work Unit 129-02-01-07
JPL 329-21101-1-3450

A. NATURAL OSCILLATIONS IN CYLINDRICAL CESIUM DIODES

During this period, electrical oscillations of spontaneous origin were examined experimentally using JPL-built cesium diodes. The objective of these experiments is to better understand the physics of thermionic energy converters, especially to explain the spontaneous oscillations that can occur in cesium diodes. Enhancement of such oscillations by applying an external magnetic field is another objective.

Three glass diodes were built at JPL for the study of oscillations. Two of the diodes had cylindrical collectors that were 1/2 in. in diameter and 2 in. in length. The other diode had a cylindrical collector that was 0.25 in. in diameter and 0.654 in. in length. This small diode was constructed to examine the effects on the oscillations of interelectrode distance and of the temperature distribution along the filament. Although both nickel and tantalum were used as anode materials, no effects on the oscillations were observed because of the different materials. Each diode was operated in a temperature-regulated oven, and the cesium reservoir temperature was determined from the equilibrium oven temperature. Filament temperatures were determined with a pyrometer. The filament was directly heated from a half-wave rectified 60-cycle current source, and volt-ampere curves were obtained during the off periods of the heating current. Waveforms and frequency spectra of the oscillations were measured across a decade resistance box that was connected in series with the diode.

Oscillations were found to occur in the plateau part of the volt-ampere curves when the emitter temperature, T_E, and the cesium reservoir temperature, T_{Cs}, were such that nearly neutral emission was occurring at the emitter surface. The amplitude of the current oscillations, which was as large as the dc current, increased as the circuit resistance was decreased until a threshold value of resistance of the order of 1 ohm was reached. Below this value, no further change occurred in the oscillation. At this point, the maxima and minima of the oscillating current were measured, and the current density was determined using the effective emitter area. Such current densities were plotted as a function of the reciprocal of the emitter temperature as shown in Fig. 1. The double-valued (hatched) parts of the curves indicate the regions where oscillations occurred. The maxima of the oscillating current follow closely the theoretical S-curves, which are shown in broken lines. These lines were drawn for current densities that were obtained from the Warner-Rasor theory for a bare metal work function of 4.65. Three features of the results shown in Fig. 1 are:

1. Oscillations occurred within narrow temperature combinations of T_E and T_{Cs}, so that the electron current density, J_e, and the ion current density, J_i, were related to the mass of the carriers by:

$$J_e/J_i \approx \sqrt{m_i/m_e} \ .$$

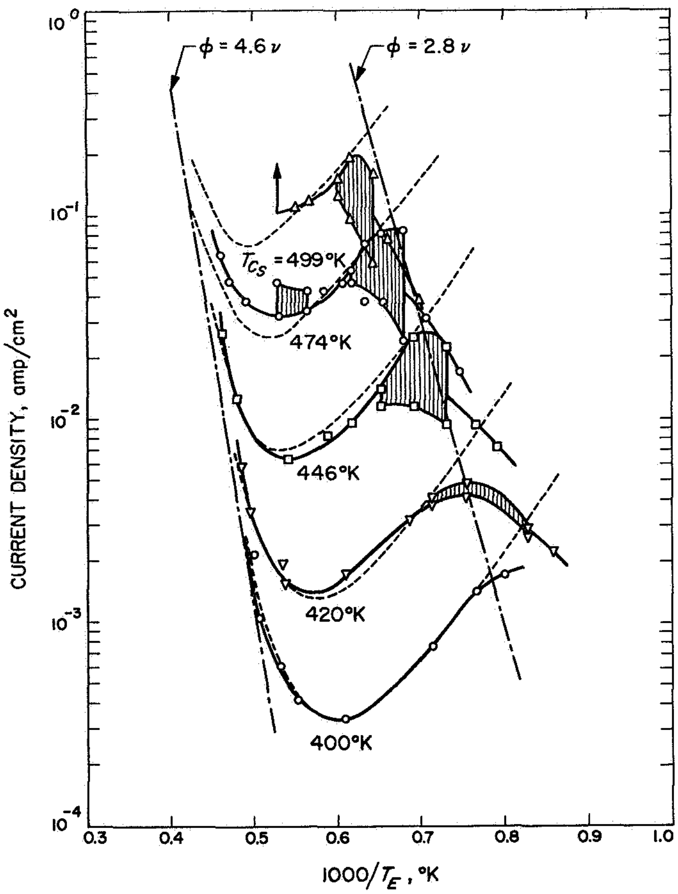


Fig. 1. Amplitude of oscillation

(W-Ta small diode)

The charge densities under such temperature combinations are neutral at the emitter surface.

2. Oscillations did not occur for very high or very low cesium reservoir temperatures. Large values of T_{Cs} result in a small mean-free-path for electrons, and this causes collisions between particles that disrupt coherent oscillations. When T_{Cs} is reduced, the current density reaches a value so that the space-charge minimum or maximum does not occur. It appears, therefore, that the formation of a collisionless space-charge is a required condition for the oscillations to exist.

3. Because the maxima of the current oscillations followed the theoretical line for temperature-saturated electron current, the peak-to-peak variation of the current can be explained in terms of a switching between two conduction mechanisms: one conduction mechanism operating at the maximum

value of the current, and another mechanism at the minimum value. The current conduction switches between the temperature-saturated value at its maximum and the space-charge-limited value at its minimum.

The variation of the depth of the potential minimum, which would have caused the observed fluctuation in current, was calculated to be of the order of 100 mv. Such a value is expected in a diode operated in a space-charge-limited mode. The results concerning the frequency of the oscillations indicated that the frequency is a function of the product of cesium pressure times interelectrode gap. Further investigation will be required to obtain more definitive conclusions concerning the frequency of the oscillations. Amplitude-modulated waveforms were observed, and were caused by the temperature distribution along the filament.

B. METAL-CERAMIC DIODE FOR USE IN AN APPLIED MAGNETIC FIELD

To study externally excited oscillations at elevated cesium reservoir temperatures up to 600°K, a metal-ceramic diode was proposed to be built. The design of a metal-ceramic diode having collectors in four identical segments was completed on contract to Electro-Optical Systems, Inc., Pasadena, California. Whether a metal-ceramic diode will be fabricated depends on the results that will be obtained on our glass diodes with an external magnetic field applied. Preliminary investigations during this period, together with work performed previously by another investigator at JPL, indicate that it may not be possible to excite the low-frequency magnetosonic oscillations in which we are interested. It is likely that the simplified theory of magnetosonic oscillations developed at JPL does not apply to the experimental diodes. Effects of a magnetic field applied to the plasma of a cesium diode operating in the arc mode are yet to be investigated.

C. CONSULTING WORK FOR THE SPACECRAFT POWER SECTION

The following consulting services were performed:

1. Technical evaluation of two proposals on low-voltage thyratrons.

2. Calculation of the internal impedance of a thermionic generator.

3. Design of a low-inductance strip line for a dc-dc converter.

4. Technical evaluation of various items for future research and development efforts in the spacecraft power section.

D. FUTURE PLANS

The possibility of exciting magnetosonic like oscillations will be investigated using glass diodes that have already been tested for spontaneous oscillations. Because we now have an additional glass diode in a smaller envelope, which enables us to wind a solenoid around the diode, external signals can be applied to excite oscillations. Results of these investigations will be reported at the International Thermionics Conference in London, September 1965, in addition to the results obtained so far.

An electron gun to be used with a proposed thermionic diode having a hot plasma emitter will be designed and tested. The design has already begun.

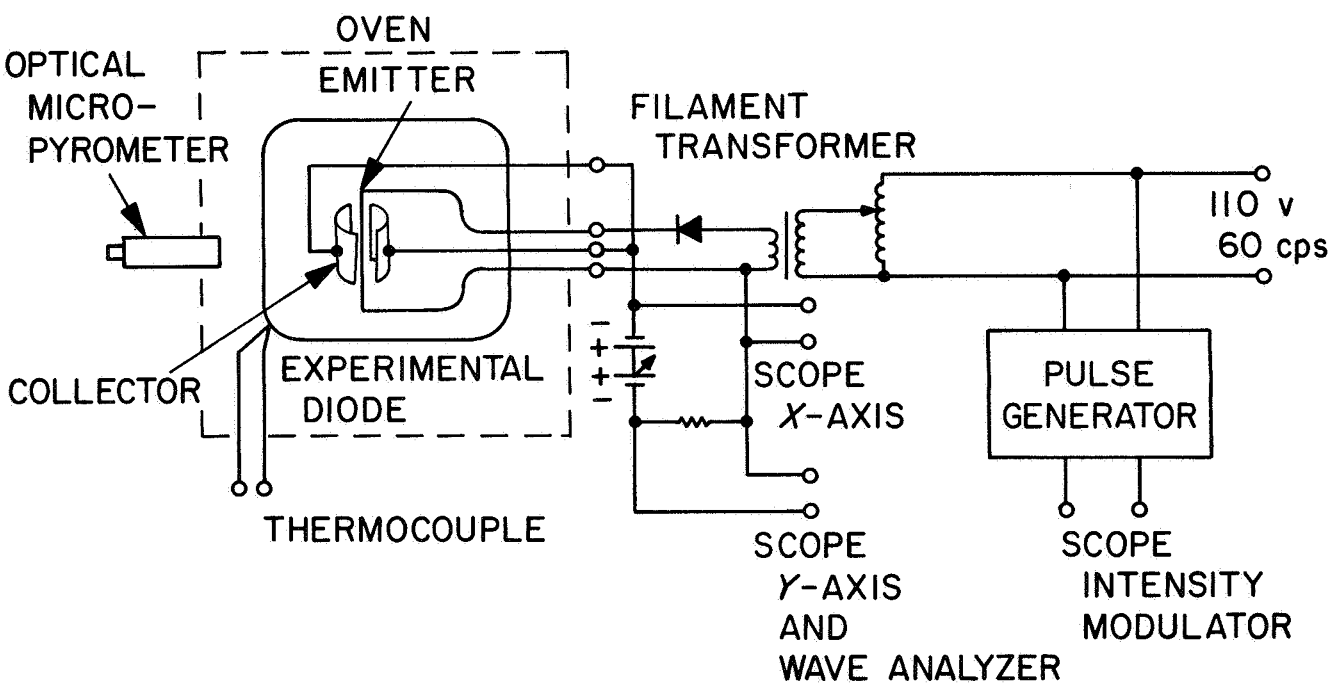
An analysis of spontaneous oscillations in cesium diodes will be made using a simplified model. Truncated velocity distributions for emitted electrons will be used in the analysis. It is hoped that we will be able to obtain a fairly simple mathematical analysis that incorporates all the various features of our interpretation of spontaneous oscillations in cesium diodes.

E. PUBLICATIONS

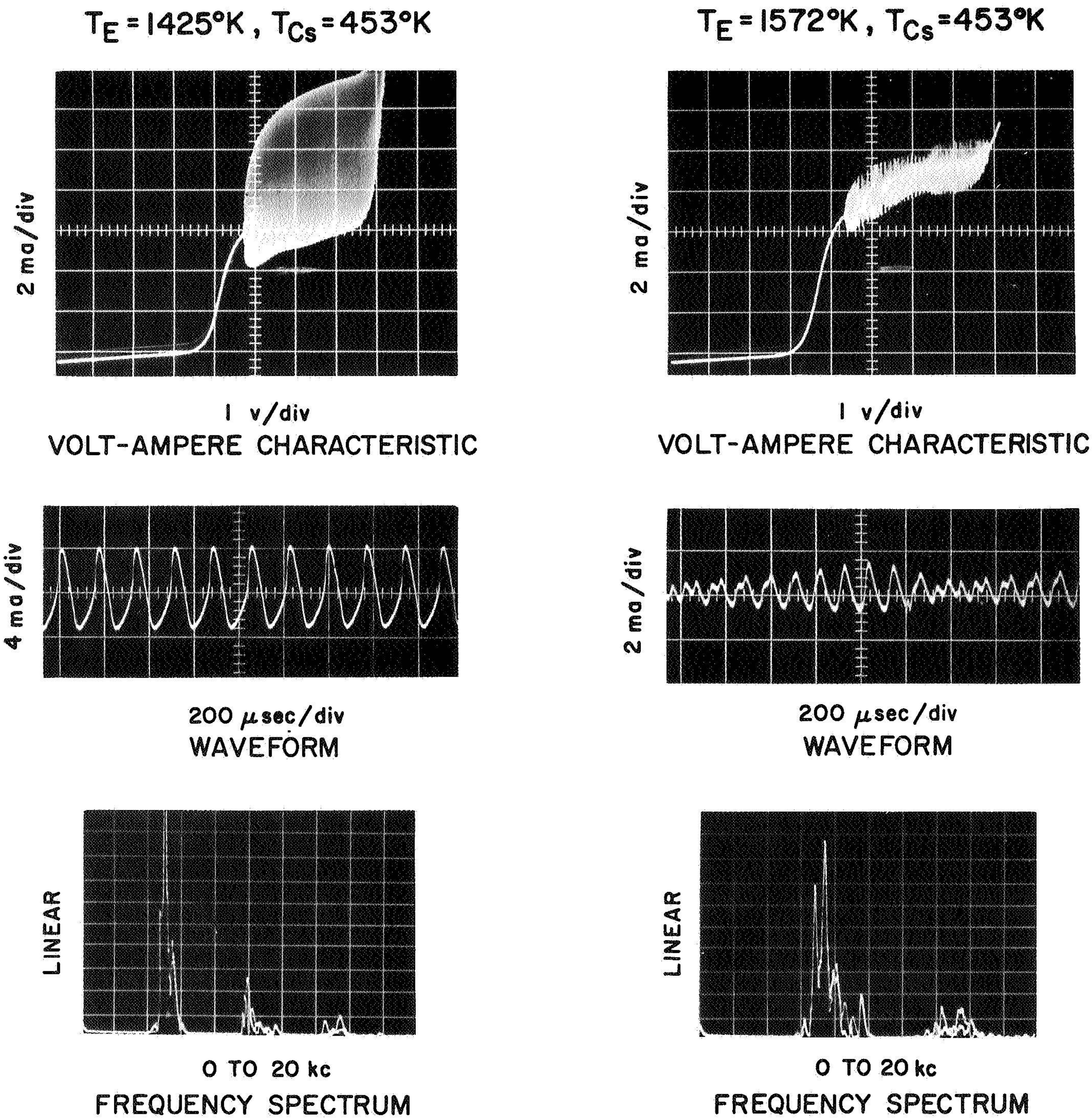
1. K. Shimada, Low-Frequency Oscillations in Cylindrical Cesium Diodes, 25th Physical Electronics Conference, Massachusetts Institute of Technology, Cambridge, Massachusetts, March 24-25, 1965.

2. K. Shimada, Self-Excited Oscillations in Cylindrical Cesium Diodes, JPL Space Programs Summary 37-33, Vol. IV (to be published).

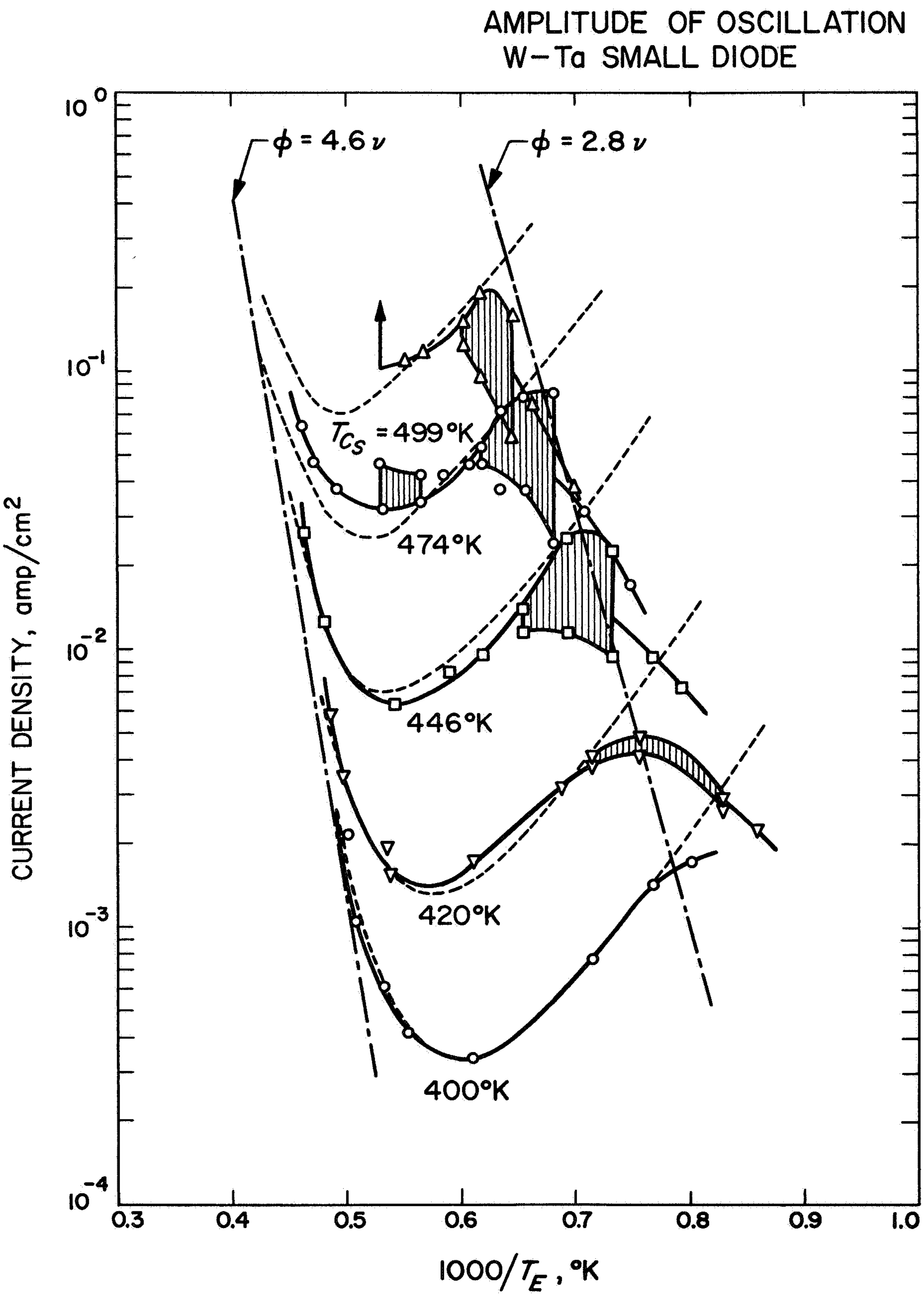
3. K. Shimada, Excitation of Low-Frequency Oscillations in Cesium Diodes, submitted to the Institution of Electrical Engineers, United Kingdom, for presentation at the International Conference on Thermionic Electrical Power Generation, London, England, September 20-24, 1965.



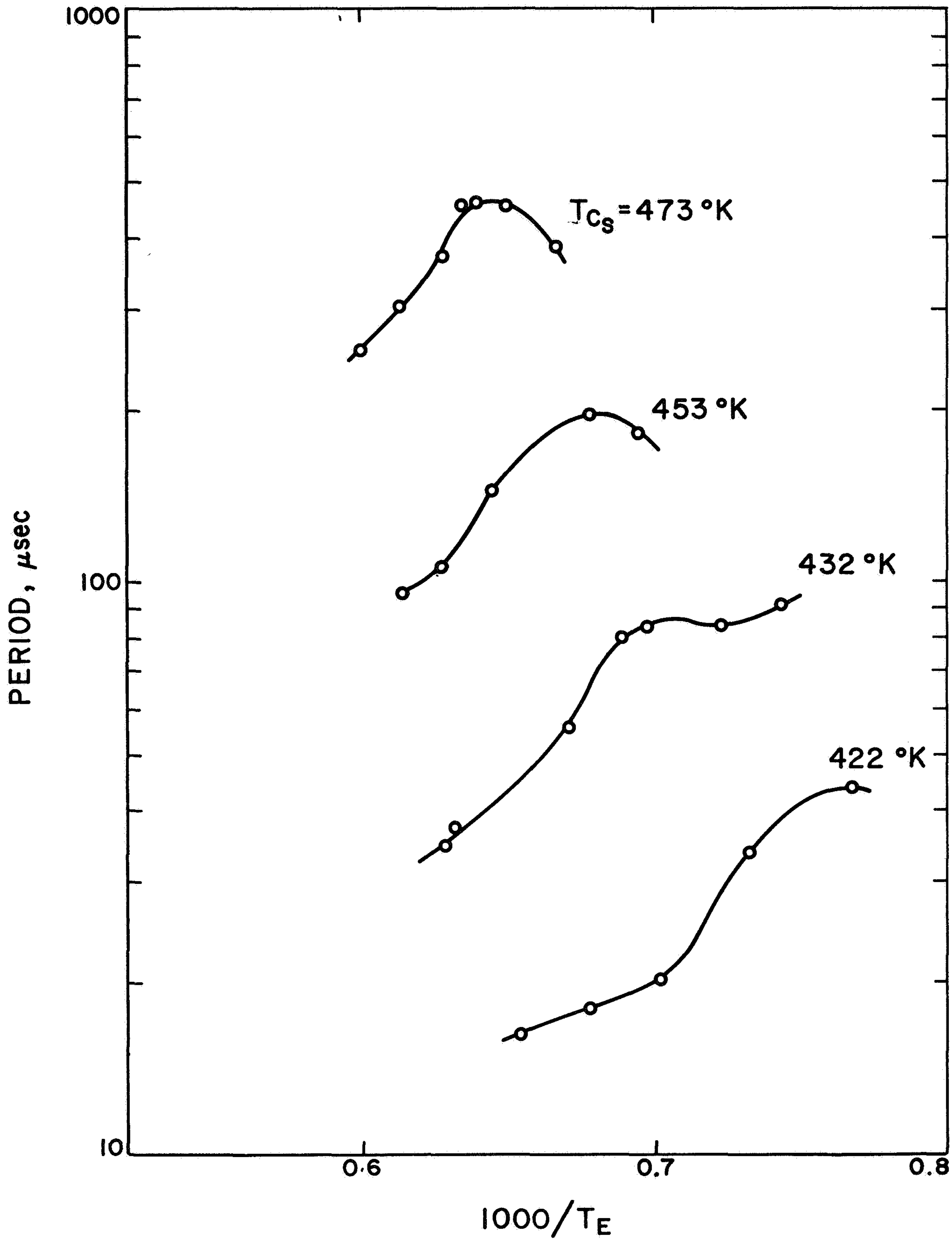
SCHEMATIC DIAGRAM OF MEASURING CIRCUIT



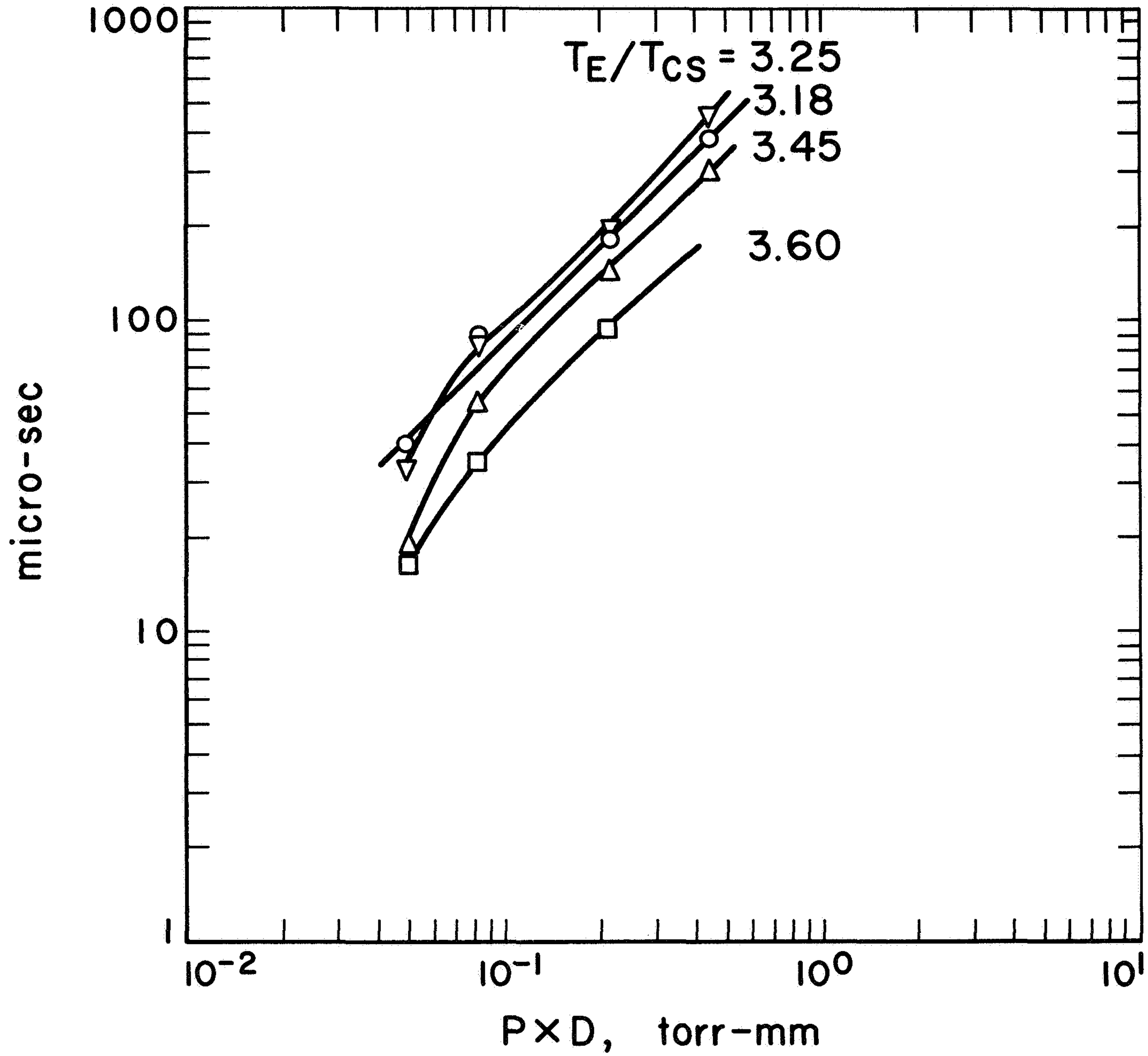
$T_E = 1425°K$, $T_{Cs} = 453°K$
$T_E = 1572°K$, $T_{Cs} = 453°K$
2 ma/div
1 v/div
VOLT-AMPERE CHARACTERISTIC
2 ma/div
1 v/div
VOLT-AMPERE CHARACTERISTIC
4 ma/div
200 μsec/div
WAVEFORM
2 ma/div
200 μsec/div
WAVEFORM
LINEAR
0 TO 20 kc
FREQUENCY SPECTRUM
LINEAR
0 TO 20 kc
FREQUENCY SPECTRUM



AMPLITUDE OF OSCILLATION
W–Ta SMALL DIODE
ϕ = 4.6 v
ϕ = 2.8 v
T_{Cs} = 499°K
474°K
446°K
420°K
400°K
CURRENT DENSITY, amp/cm²
1000/T_E, °K
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0



1000
100
10
0.6
0.7
0.8
PERIOD, μsec
1000/T_E
T_Cs = 473 °K
453 °K
432 °K
422 °K

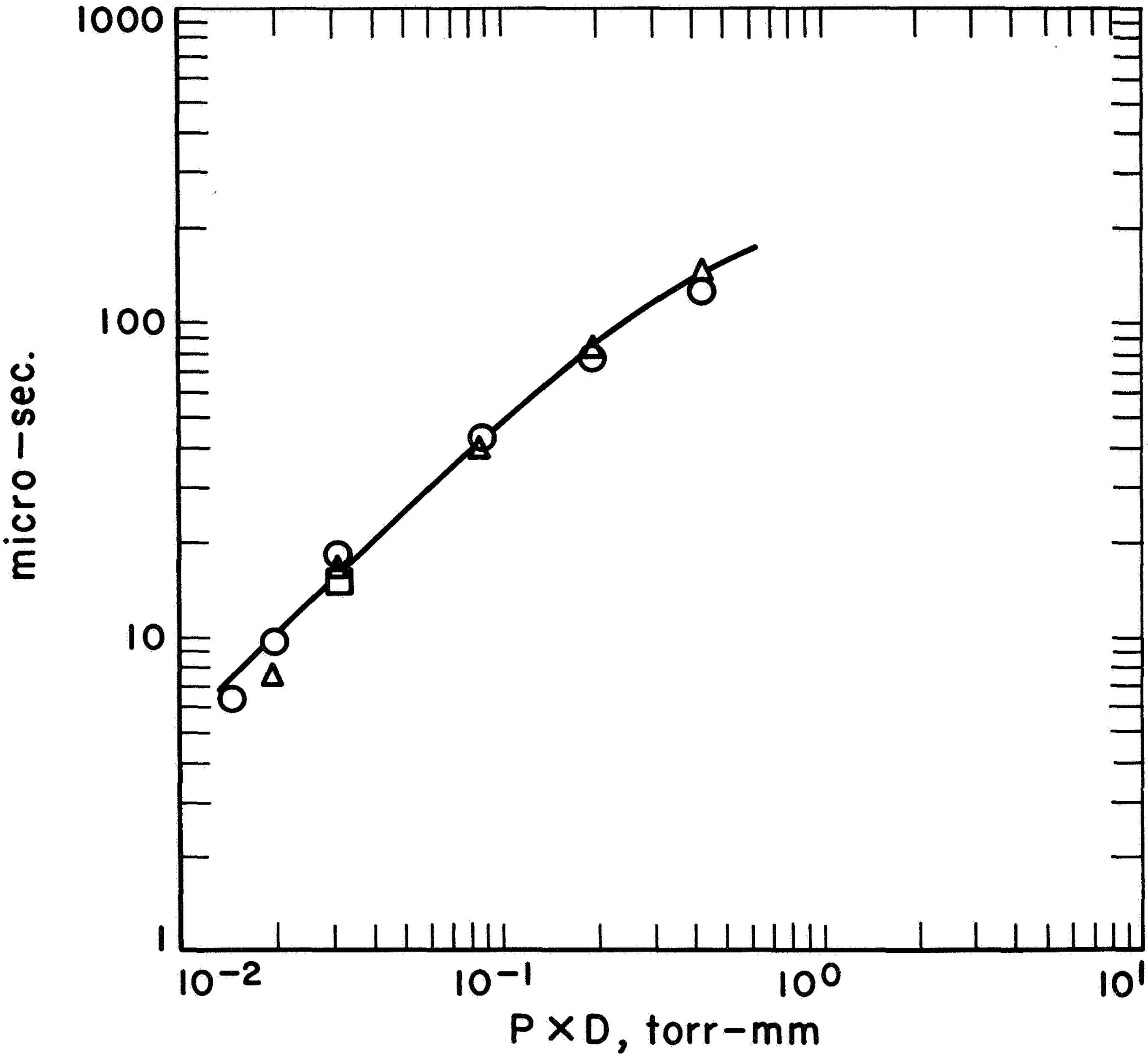


PERIOD OF OSCILLATION

vs

PRESSURE × DISTANCE

LARGE DIODE



PERIOD OF OSCILLATION vs
PRESSURE × DISTANCE, SMALL DIODE

329-21401-1-3450

RESEARCH AND TECHNOLOGY RESUME	1.	2. GOVT. ACCESSION	3. AGENCY ACCESSION NR 000579	
4. DATE OF RESUME: 01 04 65	5. KIND OF RESUME: D CHANGE	6. SECURITY: U RPT U WRK	7. REGRADING: N/A	8. RELEASE LIMITATION: NL	9. LEVEL OF RESUME: A. Work Unit

10a. CURRENT NUMBER/CODE: 129-02-05-06-55

10b. PRIOR NUMBER/CODE: (NONE)

11. TITLE: U MAGNETICS AND THERMOELECTRICS RESEARCH

12. SCIENTIFIC OR TECH. AREA: ELECTRICITY & MAGNETISM 005500; COMPUTERS 004200; SOLID STATE 015700

13. START DATE: 01 62

14. CRIT. COMPL. DATE: N/A

15. FUNDING AGENCY: NR OTHER

16. PROCURE. METHOD: C IN-HOUSE

17. CONTRACT/GRANT: N/A — a. DATE — b. NUMBER — c. TYPE — d. AMOUNT

18. RESOURCES EST.	a. PROFESSIONAL MAN-YEARS	b. FUNDS (In thousands)
PRIOR FY—65	1.5	205
CURRENT FY—66	2.0	150

19. GOVT. LAB/INSTALLATION/ACTIVITY

NAME: Jet Propulsion Laboratory
ADDRESS: 4800 Oak Grove Drive
Pasadena, California 91103

RESP. INDIV.: N. Sirri/D. I. Tchernev
TEL: 213-354- 4410

20. PERFORMING ORGANIZATION

NAME:
ADDRESS: (Same as 19)
INVESTIGATORS
PRINCIPAL:
ASSOCIATE:
TEL: TYPE:

21. TECHNOLOGY UTILIZATION

22. COORDINATION

23. KEYWORDS

Objectives. (1) To conduct research in magnetism which will lead to a better understanding of the basic operation of magnetic digital computer devices. The immediate objective is to determine the frequency of nuclear magnetic resonance as a function of density for iron oxide particles uniformly dispersed in parafin. (2) To conduct research which will lead to a better understanding of the thermoelectric effect, especially in thin films. The immediate objective is to achieve bulk thermoelectric power and resistivity in thin films.

Approach. (1) the NMR in ferromagnetic γ-Fe_2O_3 will be observed with a superheterodyne spectrometer covering the range from 10 to 100 Mc in zero magnetic field and temperatures from 4.2°K to 300°K. The resonance frequency will be used as a direct measure of the interaction among the particles when plotted vs. density (or mean distance between particles). The shift in the NMR frequency of Fe^{57} is expected to be between 1 and 100 ppm and the sensitivity and stability of the equipment is chosen accordingly. (2) The thermoelectric and resistive properties of thin films will be examined as a function of temperature in the range from 1.6°K to 400°K. Pure materials (Bi, Sb, Te, Si, Ge), and various alloys and compounds will be used. Effects of film thickness, deposition rate, substrate temperature and crystallinity will be investigated. Phonon drag and spin drag effects will be investigated at the low temperatures.

Progress. (1) C. E. Patton and F. B. Humphrey, "Wall Motion by Reverse Neel Walls in Thin Films," J. Appl. Phys. 35, 921 (March 1964); (2) C. H. Wilts, "Quasistatic Properties of RIS Films of Oxidized Permalloy," J. Appl. Phys. 35, 2097 (July 1964); (3) F. B. Humphrey and K. Kuwahara, "Magnetoresistance Investigation of RIS Films," JPL SPS 37-24, Vol. IV, Aug/Sept 1964.

27. — 28. REQUESTING AGENCY — 29. INTER-CENTER SUPPORT: N/A — 30. CROSS CODE

31. SPECIAL EQUIPMENT

32. FUNDS ($ K)	IN-HOUSE	CONTRACT
PRIOR FY—65	205	N/A
CURRENT FY—66	150	N/A
NEXT FY—		

33. UNIQUE PROJECT: Research Program, SRT (129)

34. SUB PROGRAM: Electro Physics Research (02)

35. TASK AREA: Physics of Solids (05)

NASA FORM 1122 (AUGUST 64) (OVER)
(Items 1 to 26 identical to DD Form 1498)

MAGNETICS RESEARCH
NASA Work Unit 129-02-05-06
JPL 329-21401-1-3450

During the past 6 mo, work in the magnetics area has been devoted mainly to the assembly of a superheterodyne spectrometer for the 10 to 100 Mc range. This spectrometer will have frequency stability better than 1 ppm, frequency modulation, double frequency conversion, and phase-sensitive detection. It will be capable of operation with specimen temperatures in the range from 4.2 to 300°K; however only 4.2°K (liquid helium) and 0°C (ice water), and perhaps 90°K (liquid oxygen) will be used for measurements because of the stability and reproducibility of these temperatures. The necessary parts for the spectrometer have been ordered and the assembly has been started. Because of the delay in the delivery of some parts of the equipment, the completion of the spectrometer is not expected before October 1965.

The spectrometer will be used to study the nuclear magnetic resonance (NMR) in fine particles of Fe^{57} that are uniformly dispersed in a nonmagnetic binder. The frequency of this resonance is a measure of the internal magnetic field at the site of the nucleus in the ferromagnetic particles. This internal field consists of the molecular field within each particle and the interaction field caused at the location of a particle by its neighbors. When the density of the ferromagnetic particles in the nonmagnetic binder is reduced, the mean distance between them is increased and, consequently, the interaction field is reduced. This will cause a change in the NMR frequency of the Fe^{57}. Because the molecular field in ferromagnetic materials is of the order of 10^6 oersted while the interaction field is between 0 and 100 oersted, the change in NMR frequency will be small (a few parts per million); which puts the strict requirement on the frequency stability of the spectrometer. Again, the limited natural abundance of Fe^{57} (i.e., 2%) limits the strength of the output signal and requires extreme gain with high signal-to-noise ratio. The first material to be studied will be iron oxide; however, other possible materials have been considered and will be studied later. It is expected that the spectrometer will permit the direct measurement of the strength of the interaction between particles as a function of their density, and thus enable us to determine the highest possible density of digital magnetic information storage without mutual interaction between the different bits.

THERMOELECTRIC THIN FILMS

The electrical transport properties of thin metal and semimetal films are to be studied. Thermoelectric, resistive and Hall effect measurements will be made in the temperature range from 1.6 to 425°K for films grown on crystalline and noncrystalline substrates. The electrical transport properties of copper, bismuth, antimony, and tellurium films will be studied as a function of film thickness. The conditions required for achieving bulk properties will be determined. In addition, the electrical transport properties of films formed from compounds and alloys of the above metals with each other and with other metals will be studied. The effect of compounding and alloying on the transport properties will also provide an understanding of the band structure of the metals and semimetals.

The resistance of a few bismuth films was examined during the early part of the present report period to see if bulk electrical resistivity could be obtained. These films were vapor-deposited in a borrowed vacuum system. The films had a resistivity two to three times greater than the bulk value and, also, a negative temperature coefficient indicating bulk properties had not been achieved.

A vacuum system to be used exclusively for growing films for this work will be received some time in July. The conditions necessary for achieving bulk properties will be obtained and all films will be vapor-deposited in this new vacuum system.

Construction of a system for measuring the thermoelectric and resistive properties of the films was begun in the early part of the report period. Because the scientist involved in this work was away during March, April, and May (performing an Army R. O. T. C. commitment), this system was not completed. It is expected to be completed in July.

An important result expected in this work is the achievement of thin films having higher thermoelectric output and lower resistivity than the films now used as thermoelectric infrared detectors.

PUBLICATION

Wilts, C. H., Ferromagnetic Hysteresis Instrumentation, p. 58, JPL Space Programs Summary 37-32, Vol. IV.

RESEARCH AND TECHNOLOGY RESUME

- 1.
- 2. GOVT. ACCESSION
- 3. AGENCY ACCESSION: NR 000577
- 4. DATE OF RESUME: 01 04 65
- 5. KIND OF RESUME: D CHANGE
- 6. SECURITY: U RPT U WRK
- 7. REGRADING: N/A
- 8. RELEASE LIMITATION: NL
- 9. LEVEL OF RESUME: A. Work Unit
- 10a. CURRENT NUMBER/CODE: 129-02-05-02-55
- 10b. PRIOR NUMBER/CODE: (NONE)
- 11. TITLE: U CRYOGENICS RESEARCH
- 12. SCIENTIFIC OR TECH. AREA: SOLID STATE PHYSICS 015700; NAVIGATION & GUIDANCE 010800
- 13. START DATE: 01 62
- 14. CRIT. COMPL. DATE: N/A
- 15. FUNDING AGENCY: NR OTHER
- 16. PROCURE. METHOD: C IN-HOUSE
- 17. CONTRACT/GRANT: N/A — a. DATE — b. NUMBER — c. TYPE — d. AMOUNT

18. RESOURCES EST.	a. PROFESSIONAL MAN-YEARS	b. FUNDS (In thousands)
PRIOR FY–65	2.0	200
CURRENT FY–66	2.0	175

19. GOVT. LAB/INSTALLATION/ACTIVITY

NAME: Jet Propulsion Laboratory
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Pasadena, California 91103

RESP. INDIV.: N. Sirri/J. T. Harding
TEL: 213-354- 4410

20. PERFORMING ORGANIZATION

NAME:
ADDRESS: (Same as 19)
INVESTIGATORS PRINCIPAL:
ASSOCIATE:
TEL: TYPE:

21. TECHNOLOGY UTILIZATION

22. COORDINATION

23. KEYWORDS

24 Objectives. To conduct research in low temperature physics which will lead to a better understanding of the basic operation of guidance, control and power devices. Two immediate objectives are: (1) to investigate the effects of trapped flux, the London moment, and nonsphericity in the cryogenic gyroscope; and (2) to identify the principal mechanisms for energy dissipation in liquid helium below 1°K (from a long range point of view, knowledge of this kind is essential to the development of theoretical descriptions of transport phenomena in liquid helium and in other condensed systems).

25 Approach. (1) New techniques for altering the rotor speed and field polarity without disturbing the axis of the rotor under test will be used to isolate and identify the various torque mechanisms contributing to net drift in the cryogenic gyro. The cryogenic gyro suspension will be used to measure the viscosity of liquid helium below 2°K by observing the deceleration of a rotor spinning in liquid helium. (2) Accurate measurements of sound velocity and absorption in He will be made initially at the frequencies 0.5, 1, 10, and 30 Mc/sec. Temperatures as low as 0.3°K will be achieved by using ^{3}He as a coolant in a specially-constructed cryostat. Subsequent measurements will be made at frequencies near 100 Mc/sec, and at temperatures below 0.3°K, which can be reached by adiabatic demagnetization.

Progress. (1) J. T. Harding, "Drift Data for the Cryogenic Gyroscope," 1964 Cryogenic Eng. Conf., Aug. 17-21, 1964, Phila., Pa.; (2) W. A. Jeffers and W. M. Whitney, "Temperature and Frequency Dependence of Ultrasonic Absorption in Liquid He Below 1°K," submitted to Phys. Rev.; (3) W. M. Whitney, "Identification of a Mechanism for Sound Absorption in Liquid Helium Below 1°K," p. 64, JPL SPS 37-30, Vol. IV; (4) J. T. Harding, "Elimination of Torque on a Magnetically Supported Superconducting Ellipsoid," JPL SPS 37-31, Vol. IV.

- 27.
- 28. REQUESTING AGENCY
- 29. INTER-CENTER SUPPORT: N/A
- 30. CROSS CODE
- 31. SPECIAL EQUIPMENT

32. FUNDS ($ K)	IN-HOUSE	CONTRACT
PRIOR FY–65	200	N/A
CURRENT FY–66	175	N/A
NEXT FY–		

- 33. UNIQUE PROJECT: Research Program, SRT (129)
- 34. SUB PROGRAM: Electro Physics Research (02)
- 35. TASK AREA: Physics of Solids (05)

CRYOGENICS RESEARCH
NASA Work Unit 129-02-05-02
JPL 329-20201-1-3450

CRYOGENIC GYRO

At the start of the current 6 mo reporting period, the cryogenic gyro had been brought to the stage of development so that meaningful drift data could be obtained. The primary objective during this period has been to develop techniques to evaluate the drift of the cryogenic gyro and to correlate the drift with known sources of torque.

The problem of readout has been studied. Of the various systems conceived that fulfill the requirements of an all attitude readout not involving a preferred rotor axis, the following was adapted. In this system two microscopes equipped with dark field illuminators and angular readout reticle eyepieces are used. These are mounted with their axis perpendicular to the surface of the rotor and at right angles to each other. The direction of rotary surface motion will be detected visually and aligned with the reticle eyepiece, and the angle read out on a graduated circle. The direction of the spin axis is computed as the vector cross product of the vectors describing the surface motion in the two viewing planes. An anodized grid of dots will be applied to the rotor to aid in discerning the surface motion; however, this does not place any requirements on placement of the pattern relative to the spin axis (which would be inacceptable inasmuch as the pole wanders on the rotor surface).

To separate the effect on drift of trapped flux and London moment from the effect of nonsphericity, an analysis has been made of support field configurations to determine whether reversal of the field can be achieved without losing levitation. Several solutions to this problem have been demonstrated but none are altogether desirable. A choice must be made between techniques for slow deformation of the field configuration vs rapid reversal of the field polarity with no intermediate change in configuration. To study this problem, the restoring forces on a diamagnetic sphere in a magnetic field have been calculated for the most general case. The solution will appear in a forthcoming Space Programs Summary.

In addition, a solution to the calculations of torques on a superconducting sphere containing arbitrary trapped flux has been obtained and will appear in Space Programs Summary No. 37-33 Vol. IV. This complements the calculations of torque on an imperfect sphere (Space Programs Summary 37-24 Vol. IV p. 35), which were confirmed experimentally for an ellipsoid as described in Space Programs Summary 37-31 Vol. IV p. 92.

Additional drift data has been obtained using twice-per-day polar readout for rotors spinning perpendicular to Earth's polar axis. Drift data varied between 4 and 20 deg/day. In one experiment, the rotor was spun nearly about the Earth's polar axis and the rotor pole was observed continually over a 31-hr period. The result was an expected ellipse with a closure error of about 1 hr.

During the next 6 mo period, the techniques described above will be developed further and used to quantitatively determine the torque because of nonsphericity, the torque because of trapped flux, the torque because of the London moment, and any residual torque that may remain after these sources of torque have been accounted for.

VELOCITY AND ATTENUATION OF SOUND IN LIQUID HELIUM

This work is concerned with sound propagation in liquid helium below 1°K over a wide range of frequencies. During the past 6 mo we have completed the construction of a cryostat in which temperatures extending to 0.3°K will be reached and maintained. The design is based on that of similar devices described in the literature. The gas ^3He, which is contained and circulated within a closed system, is condensed at a temperature of approximately 1.3°K into a reservoir in contact with the bath of liquid ^4He in which the ultrasonic apparatus is immersed. Lower temperatures are achieved by evacuating the space surrounding the ^3He reservoir and the inner bath, to isolate them thermally from the outer ^4He bath, and then pumping on the ^3He.

Tests of the system have been made during the past 3 mo. The design of the ^3He circulation system and all the auxiliary apparatus has proved to be very satisfactory, but the part of the cryostat in which the ^3He reservoir is placed will require modification. The heat leak into the inner bath is much higher than was anticipated: 5 to 10 mw, as compared with what had been regarded as a conservatively-estimated upper limit of 1 mw; and the lowest temperature reached to date is 0.5°K. During the past few weeks we have been trying to find the unknown heat source. Our present conclusion is that heat is carried from the outer bath to the ^3He reservoir by sustained oscillations, somewhat like those that occur in a Helmholtz resonator, in the tube connecting the reservoir to the outer bath. In one experiment, in which we were able to inhibit the oscillations, the heat leak into the reservoir was 0.03 mw, well within our original estimate. Unfortunately, we could not measure the ultimate temperature reached during this run, but we estimate that it was in the neighborhood of 0.3 to 0.4°K. The ^3He reservoir is now being dismantled so that appropriate changes can be made.

A paper titled "Temperature and Frequency Dependence of Ultrasonic Absorption in Liquid Helium below 1°K," by W. A. Jeffers, Jr. and M. W. Whitney, was submitted to the Physical Review in March and is scheduled to appear in the August 14, 1965 issue. Analysis made in the preparation of this paper shows that it is the high-frequency behavior of the velocity and attenuation that is now of main interest, and the original plans to make measurements at frequencies below 1 Mc have accordingly been changed. The experiments will be made initially at 10 Mc, and will be extended, if possible, to frequencies well above 100 Mc.

A paper titled "Velocity of Sound in Liquid Helium II" is being written in collaboration with C. E. Chase of the National Magnet Laboratory, M.I.T., and will be submitted to the Physical Review during the next 6-mo period.

PUBLICATIONS

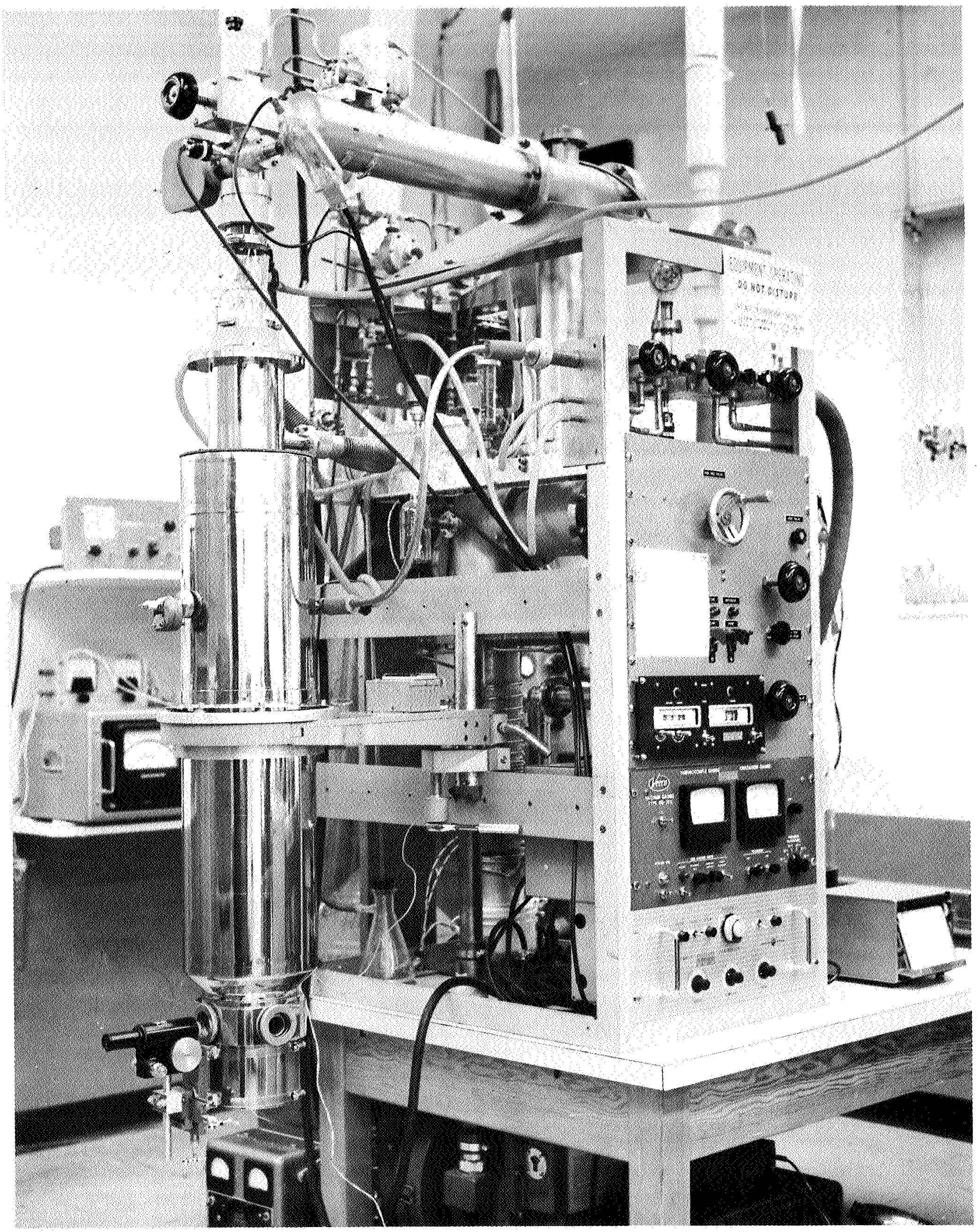
1. Whitney, W. M., Identification of a Mechanism for Sound Absorption in Liquid Helium Below 1°K, p. 64, JPL Space Programs Summary 37-30, Vol. IV.

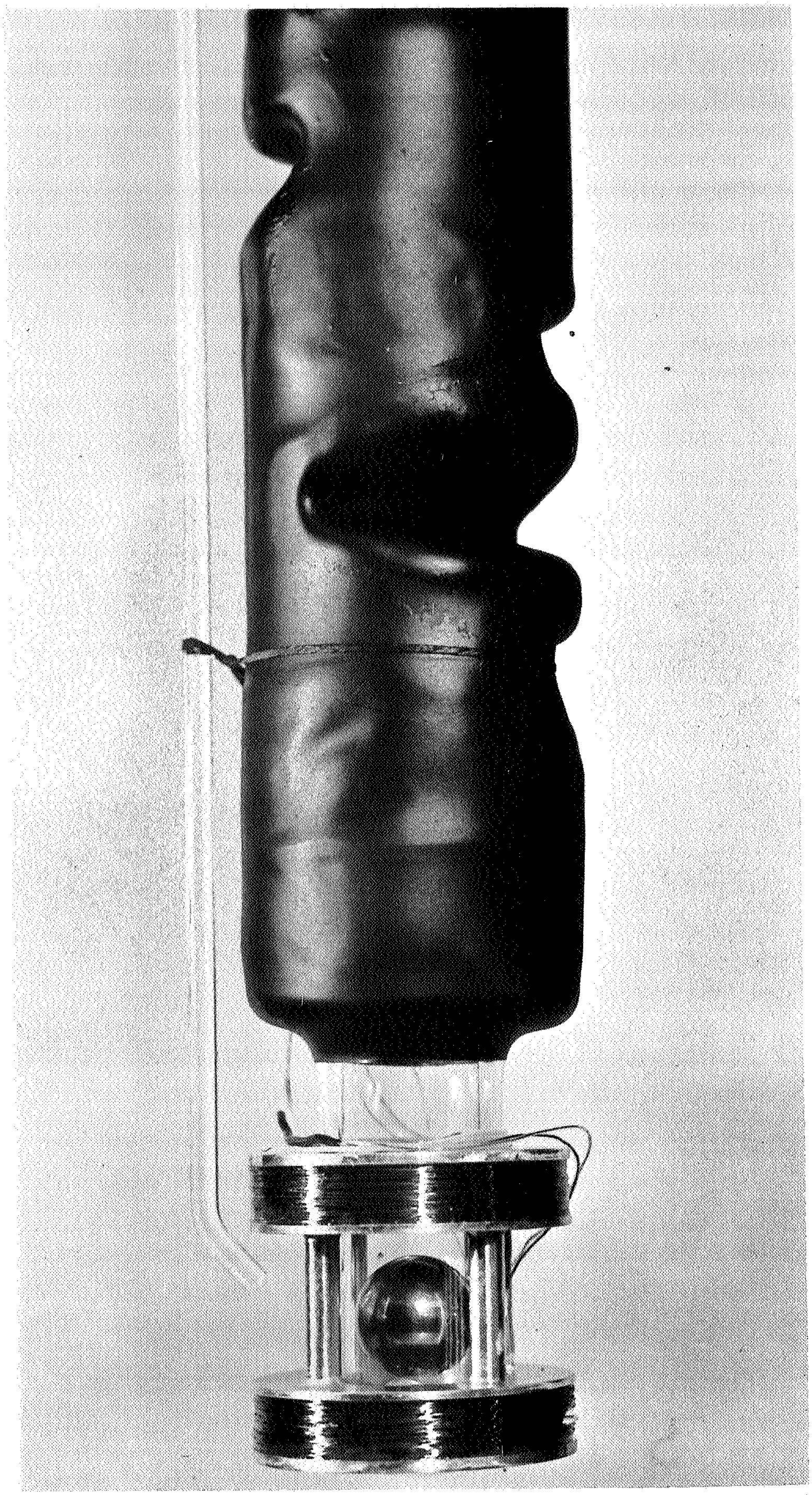
2. Harding, J. T., Analysis of Torques Exerted on a Spherical Superconductor Due to Trapped Flux in an Axially Symmetric Magnetic Field, JPL Space Programs Summary 37-33, Vol. IV., to be published.

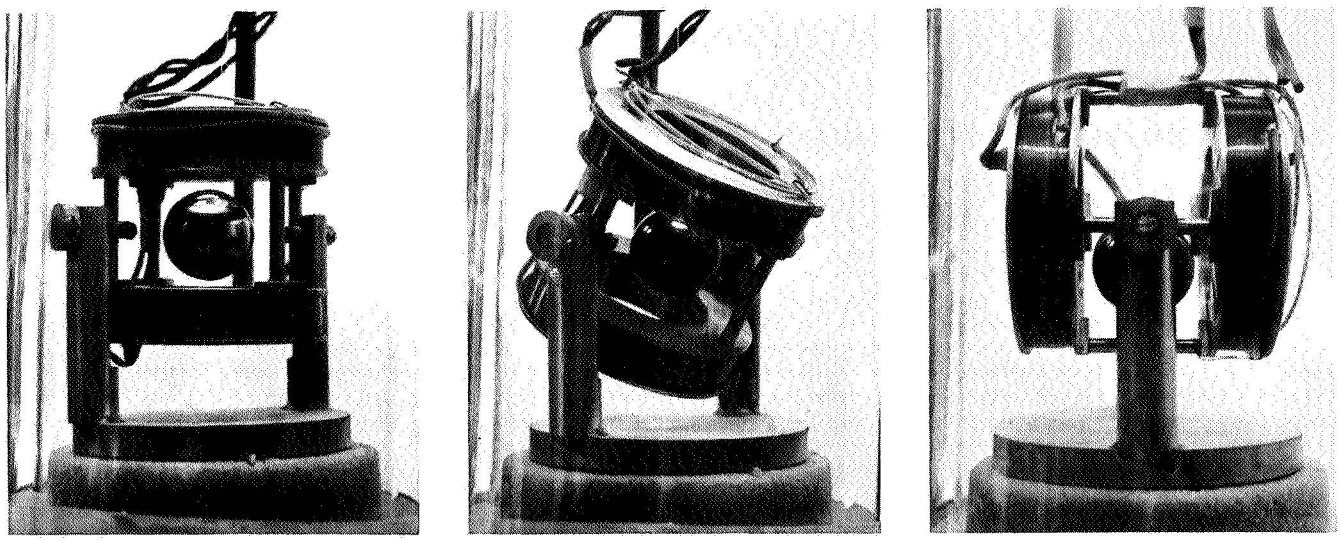
3. Harding, J. T., "Drift Data for the Cryogenic Gyro," International Advances in Cryogenic Engineering (Plenum Press, New York, 1965), Vol. X, p. 137.

CRYOGENIC GYRO: ENGINEERING TASK AREAS

1. ROTOR-MATERIAL AND FABRICATION
2. SUPPORT FIELD CONFIGURATION
3. SPIN-UP
4. READ-OUT
5. DAMPING ROTOR VIBRATION
6. MAINTENANCE OF CRYOGENIC TEMPERATURE


DO NOT DISTURB





LEVITATION OF 1" Dia. NIOBIUM ROTOR IN FIELD
PRODUCED BY "MAXWELL'S GRADIENT PAIR"
(7000 AMP-TURN PER COIL)

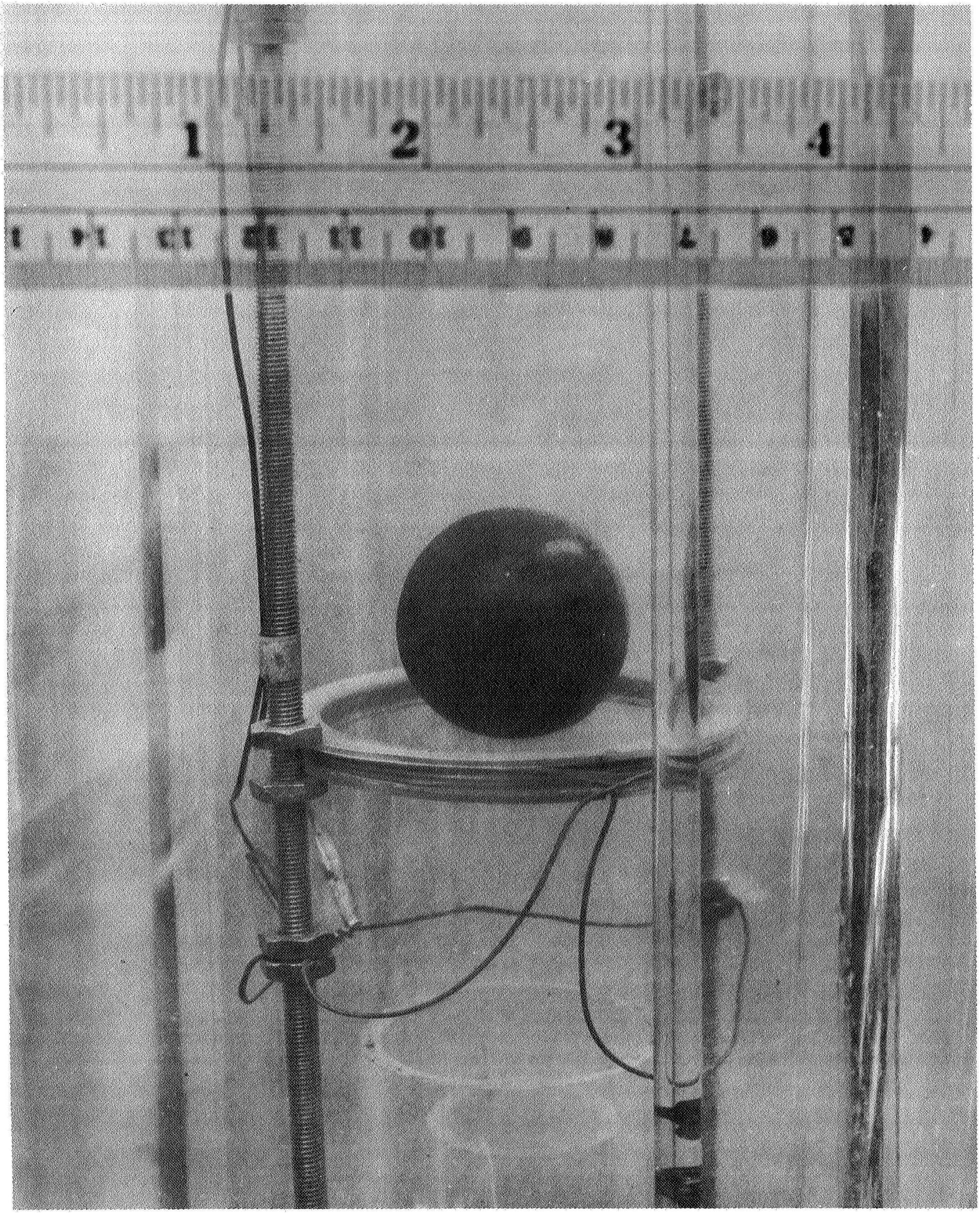
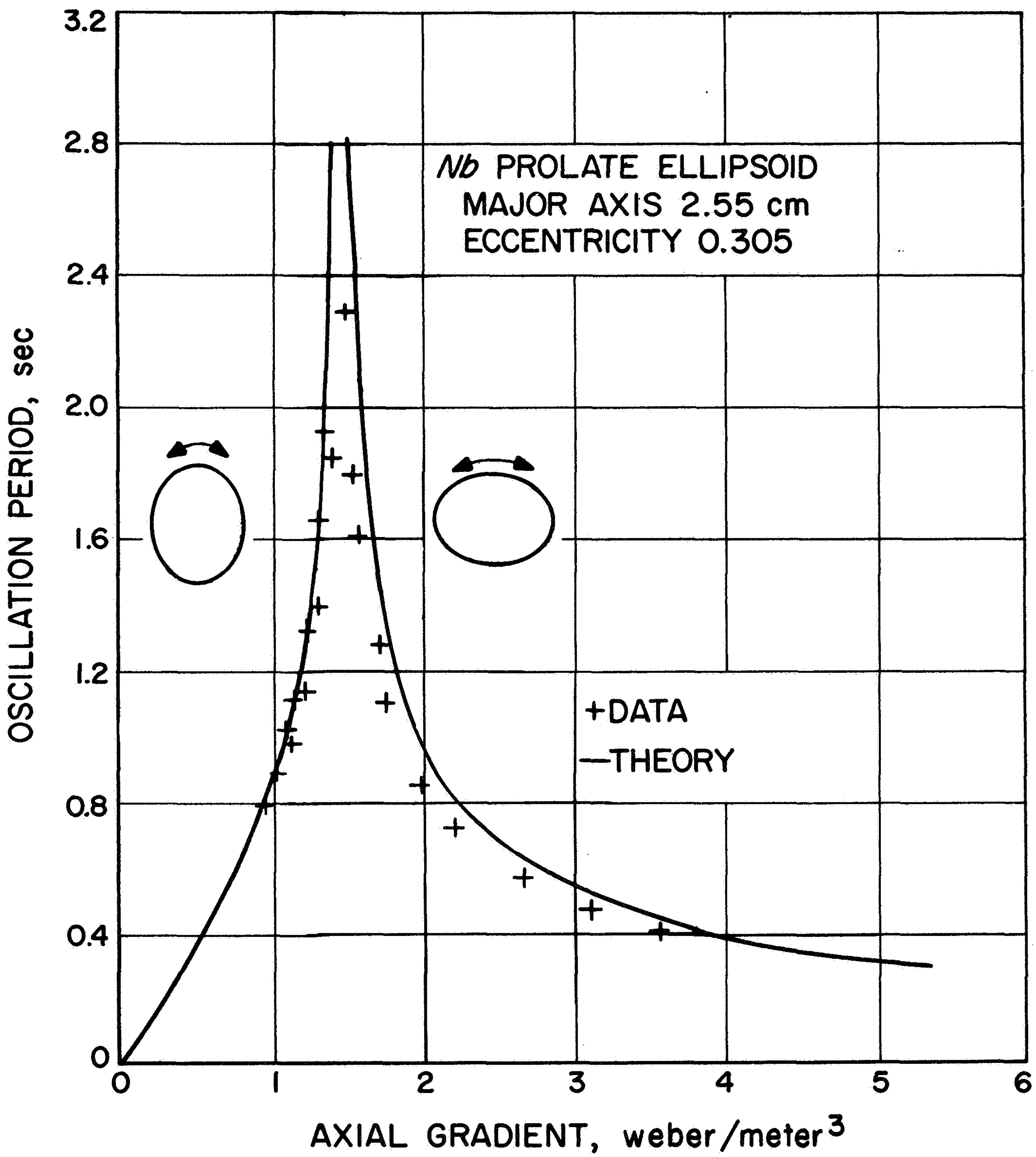
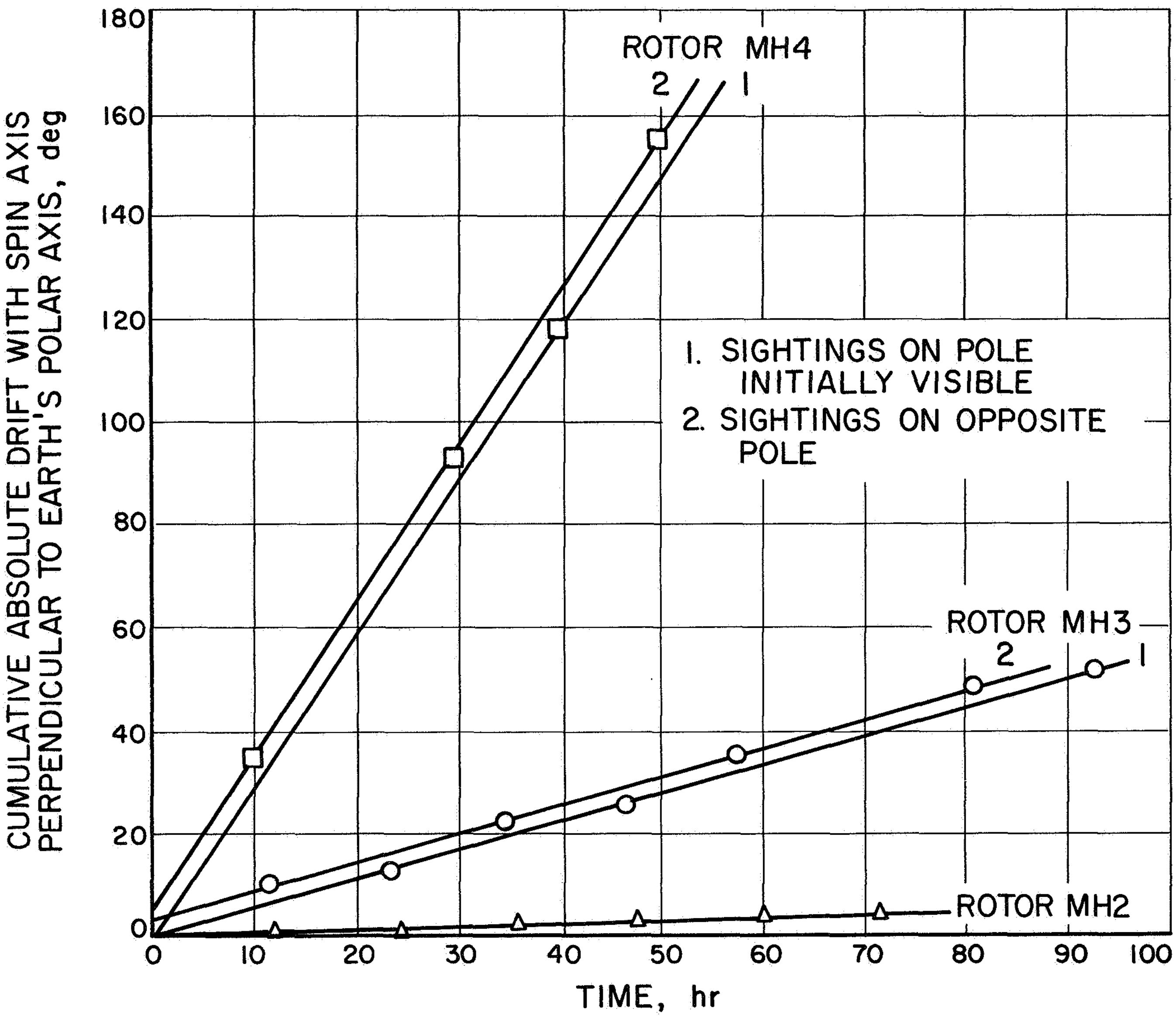
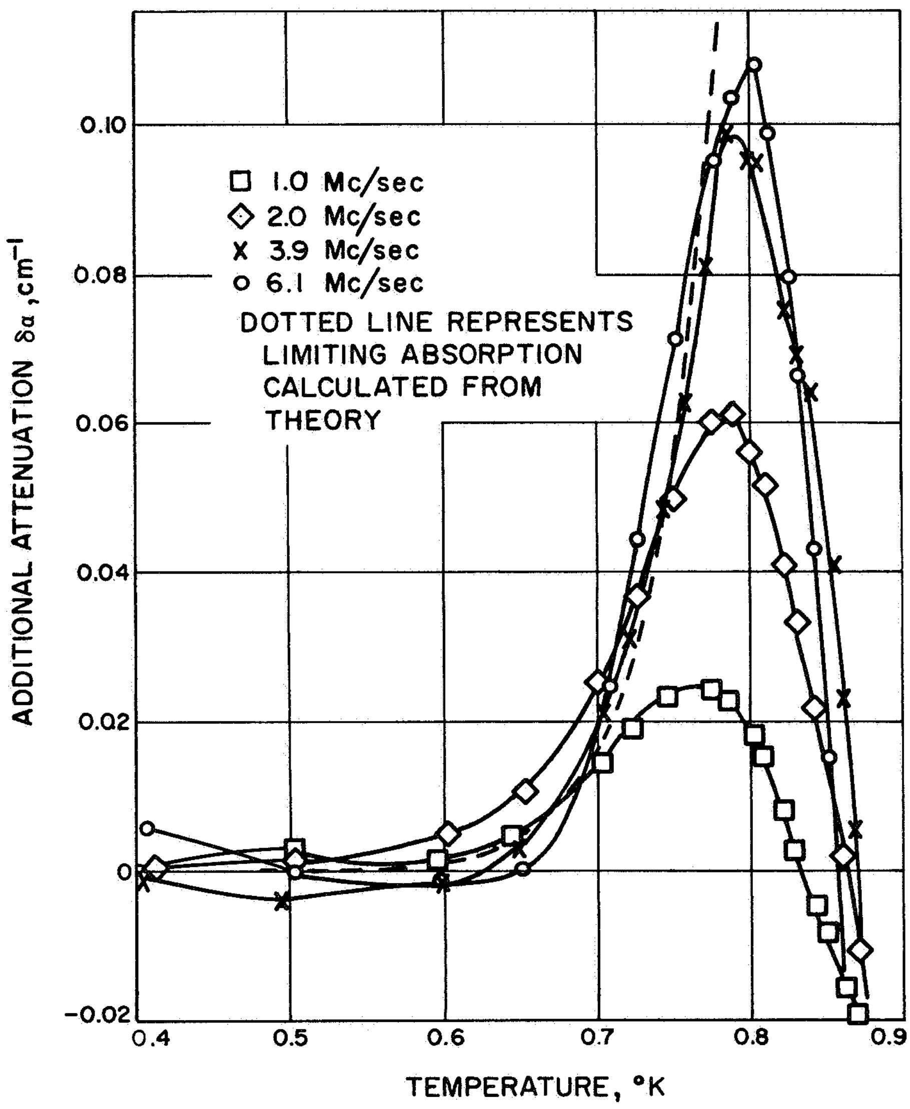

1
2
3
4

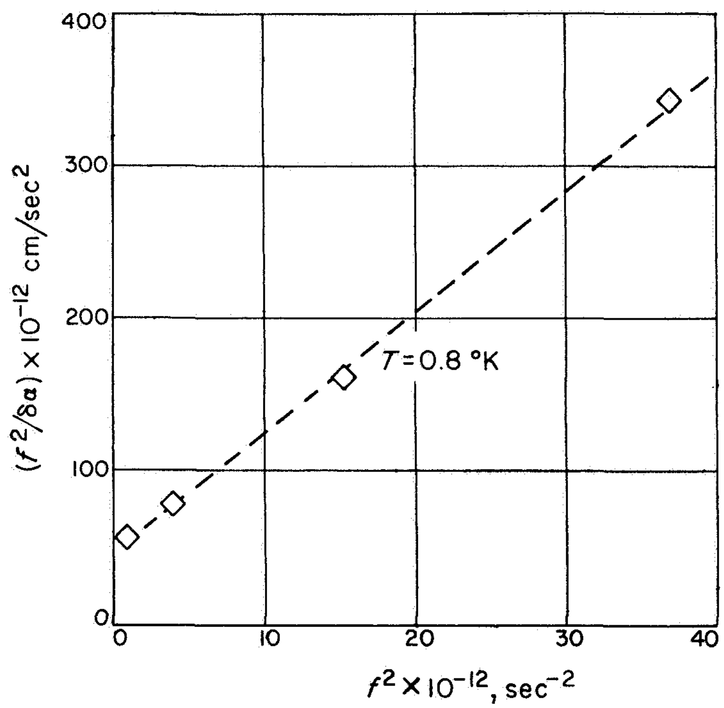
Fig. 2 RESTORING FORCES ON LEVITATED SUPERCONDUCTING SPHEROID





ROTOR MH4
2
1
1. SIGHTINGS ON POLE INITIALLY VISIBLE
2. SIGHTINGS ON OPPOSITE POLE
ROTOR MH3
2
1
ROTOR MH2
CUMULATIVE ABSOLUTE DRIFT WITH SPIN AXIS PERPENDICULAR TO EARTH'S POLAR AXIS, deg
TIME, hr
0
20
40
60
80
100
120
140
160
180
0
10
20
30
40
50
60
70
80
90
100


1.0 Mc/sec
2.0 Mc/sec
3.9 Mc/sec
6.1 Mc/sec
DOTTED LINE REPRESENTS LIMITING ABSORPTION CALCULATED FROM THEORY
ADDITIONAL ATTENUATION δα, cm⁻¹
0.10
0.08
0.06
0.04
0.02
0
-0.02
0.4
0.5
0.6
0.7
0.8
0.9
TEMPERATURE, °K


400
300
200
100
0
0
10
20
30
40
T = 0.8 °K
(f²/δα) × 10⁻¹² cm/sec²
f² × 10⁻¹², sec⁻²

329-21801-1-3450

RESEARCH AND TECHNOLOGY RESUME	1.	2. GOVT. ACCESSION	3. AGENCY ACCESSION NR 000581	
4. DATE OF RESUME 01 04 65	5. KIND OF RESUME D CHANGE	6. SECURITY U RPT U WRK	7. REGRADING N/A	8. RELEASE LIMITATION NL	9. LEVEL OF RESUME A. Work Unit

10a. CURRENT NUMBER/CODE	10b. PRIOR NUMBER/CODE
129-02-05-09-55	(NONE)

11. TITLE: U SEMICONDUCTOR RESEARCH

12. SCIENTIFIC OR TECH. AREA	13. START DATE	14. CRIT. COMPL. DATE	15. FUNDING AGENCY
SOLID STATE PHYSICS 015700; ELECTRONIC COMPONENTS 004200	12 64	N/A	NR OTHER

16. PROCURE. METHOD	17. CONTRACT/GRANT	18. RESOURCES EST.	a. PROFESSIONAL MAN-YEARS	b. FUNDS (In thousands)
C IN-HOUSE	N/A; a. DATE; b. NUMBER; c. TYPE; d. AMOUNT	PRIOR FY-65	0.8	80
		CURRENT FY-66	2.0	160

19. GOVT. LAB/INSTALLATION/ACTIVITY

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RESP. INDIV.: N. Sirri/A. Shumka
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20. PERFORMING ORGANIZATION

NAME:
ADDRESS: (Same as 19)
INVESTIGATORS PRINCIPAL:
ASSOCIATE:
TEL: TYPE:

21. TECHNOLOGY UTILIZATION

22. COORDINATION

23. KEYWORDS

24. Objectives. To do research in semiconductor physics leading to a better understanding of various electronic devices. Two immediate objectives are: (1) to obtain and investigate space-charge-limited electron current flow in Ge; and (2) to explain the mechanisms of electronic conduction and charge storage in thin films of titanium oxide.

Approach. (1) Alloyed $n^+ \pi n^+$ solid-state diodes (similar to a transistor with a floating base) of various base widths will be fabricated in the laboratory. Measurements will include base width, punch-through voltage, and impurity profile. Current-voltage characteristics of these structures will be measured at ambient temperatures ranging from 78°K to 300°K to check the theoretical variation of space-charge-limited current with temperature. These characteristics will be analyzed for space-charge-limited electron current flow in order to demonstrate that this phenomenon is possible in Ge. (2) Thin film structures consisting of a layer of titanium oxide (300 to 3000 Å thick) sandwiched between layers of aluminum will be fabricated. Optical and electrical measurements will then be made on these structures. These include: (1) thickness by optical interference methods, (2) dielectric constant (separated from effects of electronic space charge), (3) index of refraction, (4) optical transmission versus wavelength, (5) photo response vs. wavelength, (6) electronic charge-storage effects in addition to true plate capacitance, (7) current-voltage characteristics under transient and steady-state conditions, (8) temperature dependence of all electrical measurements. The optical measurements relate to the electrode-oxide barrier and to the band structure in the oxide films. The experimental results will be explained by a model based on the dominating influence of defect states, or traps, in the forbidden band.

Progress. Since this work was started in December 1964, there are no publications. Construction of laboratory apparatus is nearly completed.

27.	28. REQUESTING AGENCY	29. INTER-CENTER SUPPORT	30. CROSS CODE
		N/A	

31. SPECIAL EQUIPMENT

32. FUNDS ($ K)	IN-HOUSE	CONTRACT
PRIOR FY-65	80	NA
CURRENT FY-66	160	NA
NEXT FY-		

33. UNIQUE PROJECT	Research Program, SRT	(129)
34. SUB PROGRAM	Electro Physics Research	(02)
35. TASK AREA	Physics of Solids	(05)

NASA FORM 1122 (AUGUST 64)
(Items 1 to 26 identical to DD Form 1498)

(OVER)

SEMICONDUCTOR RESEARCH
NASA Work Unit 129-02-05-09
JPL 329-21801-1-3450

SPACE-CHARGE-LIMITED CURRENT IN GERMANIUM

During the report period, several $n^{+}\pi n^{+}$ solid-state diodes were fabricated. Junction I-V characterizations, and punch-through voltage measurements were made to evaluate the electrical properties of these alloyed solid-state diodes. The results indicate that solid-state diodes of various punch-through voltages, and with excellent reverse-biased junction electrical characteristics, can be readily fabricated. However, there appears to be an inconsistency between sample base-widths as calculated from the I-V characteristic and the punch-through voltage, which is now being resolved by metallurgical analysis of the junction regrowth surfaces of the alloyed regions. Preliminary metallurgical observations show that the regrowth surfaces of the alloyed regions exhibit a grain structure. Improvements in the alloying techniques are being introduced to eliminate this type of regrowth. A metallurgical cross-section of one sample was made and the junction boundaries displayed by a chemical etchant were flat and parallel.

A chemical hood for cleaning and etching of the solid-state diodes and a clean station for a dust-free environment were installed. A vacuum evaporator will be purchased during the next report period for vacuum deposition of masks and alloying material onto the π-type germanium wafers.

During the next report period, metallurgical observations (on more solid-state diodes) will be performed to resolve the base-width calculation inconsistency and to improve the alloying operation. A systematic electrical characterization of all fabricated solid-state diodes will be made to determine geometrical and electrical symmetries of the junctions. Measured space-charge limited-electron current at various ambient temperatures (26 to -195°C) will be evaluated and compared with the results already obtained for the hole current. Bulk minority charge carrier drift mobility measurements of the Shockley-Haynes type in the π-type germanium will be made. The n^{+} and the p^{+} alloying technologies already developed and used individually at JPL will be exploited together to fabricate $n^{+}\pi p^{+}$ structures that are very useful for studying two carrier space-charge-limited current.

TITANIUM OXIDE THIN FILMS

The purpose of this investigation has been to explain the mechanisms of electronic conduction and charge storage in titanium oxide thin films. It is anticipated that this will also lead to a better understanding of other insulating or semi-insulating thin films because they share many similar properties. The absence of a satisfactory theory for explaining much of the related experimental work in the literature, dating back many years, has required that this study place particular emphasis on the formulation of such a theory. To develop the physical basis of the theory, it was necessary to obtain reliable experimental data with which to make comparisons. Therefore, the initial phase of this work has been to accumulate the necessary experimental data and this has been followed by a critical search for a consistent theoretical explanation.

The initial experimental work was performed in most part prior to the report period, with only certain supplementary data being added during the period. A description of the experimental method used in this program has been reported (Ref. 1). Additional work performed by the principal scientist before the formation of the program at JPL has also provided useful data (Ref. 2). During this report period, several physical models were examined to seek a theoretical basis for explaining the experimental results previously obtained. More specifically, a mechanism was sought that would account for the observed electrical properties in thin film samples of metal-titanium oxide-metal sandwich configurations, and that would also be consistent with the other measured properties. It is believed that this effort has been successful because the physical model derived does provide a consistent overall picture of the results and has survived more exacting quantitative tests so far. The basic ideas for the physical model, the assumptions imposed, and some theoretical consequences are briefly described below. It may be helpful to first mention two well-known theories that have been applied to thin films with questionable success and then only in certain limiting cases.

One well-known theory involves pure electron tunneling between the metal contacts. This theory can be expected to apply only in extremely thin films (less than the order of 40 Å) and serious departures are found here between theory and experiment. The other theory involves thermionic emission of electrons from the metal over the metal-insulator barrier (often referred to as Schottky emission when the effects of image forces are included). In both theories, the insulating film is conventionally treated almost identical to a vacuum except for appropriate changes in barrier height (metal-insulator work function), dielectric constant, and electron effective mass. The ideal free electron concept is thus assumed valid.

One important consideration about the physical model derived involves the failure of the usual free electron concept. This can arise independent of the structural quality of the films treated (experimentally shown to be quasi-amorphous). This is justified because of the polaron theory developed in recent years, which treats an electron in a polar lattice as a new quasi particle consisting of an electron coupled to a cloud of optical phonons. The effect of strong coupling (which applies here) is to severely reduce the electron mobility and mean-free-path so the electron in the polar lattice can no longer be considered free, but moves very slowly; essentially tied to the conduction band edge (more correctly, to the polaron band). Even if the polaron coupling is not very strong in single crystals, the effect would be greatly enhanced in quasi-amorphous films because of the initial reduction in electron mobility by defect scattering.

Another important consideration involves the effect of high densities of defects or correspondingly high densities of impurity states within a forbidden band. This can lead to large space-charge effects even in very thin films when the occupancy of the impurity states is altered by the presence of metal contacts or applied fields. The titanium oxide films provide an interesting limiting case in this respect. The titanium oxide will quite readily undergo a reversible oxidation-reduction reaction; i.e., 6 TiO_2 6 Ti_2O_3+ $3O_2$ + (26 kcal/mole). A moderate reduction process applied to bulk single crystals of insulating rutile $(Ti)_2$), e.g., 15 min at 700°C in H_2, will produce extremely high densities of oxygen vacancies in excess of $10^{20}/cm^3$ that act as donor impurities, converting the rutile into a degenerately doped n-type semiconductor. This effect saturates at about 5 atomic % ($1.6 \times 10^{21}/cm^3$) before structural changes occur. It is reasonable to expect correspondingly high densities of oxygen vacancies to occur in the thin films that are necessarily deposited in the presence of a low partial pressure of oxygen. This consideration leads to a physical model that treats the TiO_2 films as degenerately doped semiconductors and provides a limiting case for the effect of impurities that can also be important to a less drastic extent in other materials.

The above considerations lead to a band structure for the isolated TiO_2 film such as that illustrated in Fig. 1a. The material as shown is degenerate, i.e., the Fermi level lies slightly above the smeared-out edge of the conduction band. However, the conductivity is extremely low when compared with degenerately doped nonpolar semiconductors such as silicon because of the small polaron mobility, yet sufficiently large to permit excessive conduction in thin films. The presence of metal contacts produces barriers consisting of positive space-charge layers adjacent to the two interfaces as shown in Fig. 1b. The interface barrier height, ν_o (metal to oxide work function), has often been determined from elementary considerations by the difference in the work function of the metal and the electron affinity of the oxide, but usually is fixed by interfacial states. Such a space-charge layer is often referred to as a Schottky barrier, and was the subject of much controversy (in the early 1930's) for metal oxide point contact rectifiers. The theories developed in that period, although closely related to the theory derived in this work, were not carried far enough to account for the conduction processes considered. The large space-charge density assumed here results in very narrow Schottky barriers, of the order of 30 Å; which allows electron tunneling to occur between the metal contact and the oxide interior. Furthermore, the shape of the barrier results in a process intermediate between that of pure tunneling and thermionic emission, and leads to a temperature-dependence in good agreement with the previously unexplained experimental data. This model is seen to result in a structure consisting of two Schottky barriers back-to-back. Under applied voltage, the voltage divides between them and across the interior in such a way as to maintain a constant current through the structure. Either the first or second barrier can dominate depending on the applied voltage and temperature. An interesting dependence of capacitance on temperature, voltage, and frequency results from this model. An equivalent circuit for the structure is given in Fig. 2, which serves to suggest the type of dependence. More complicated situations arise when the two contacts are not equivalent.

A qualitative and semi-quantitative comparison between theory and experiment gives satisfactory agreement, as already mentioned. A more detailed comparison is in process and the results will be given in a future report.

During the report period, the author attended the IEEE-sponsored Solid State Device Research Conference at Princeton, New Jersey. The conference is a closed meeting that discusses only the most recent unpublished research on solid-state devices.

REFERENCES

1. Maserjian, J., Titanium Oxide Thin Films, p. 98, JPL Space Programs Summary 37-31, Vol. IV.

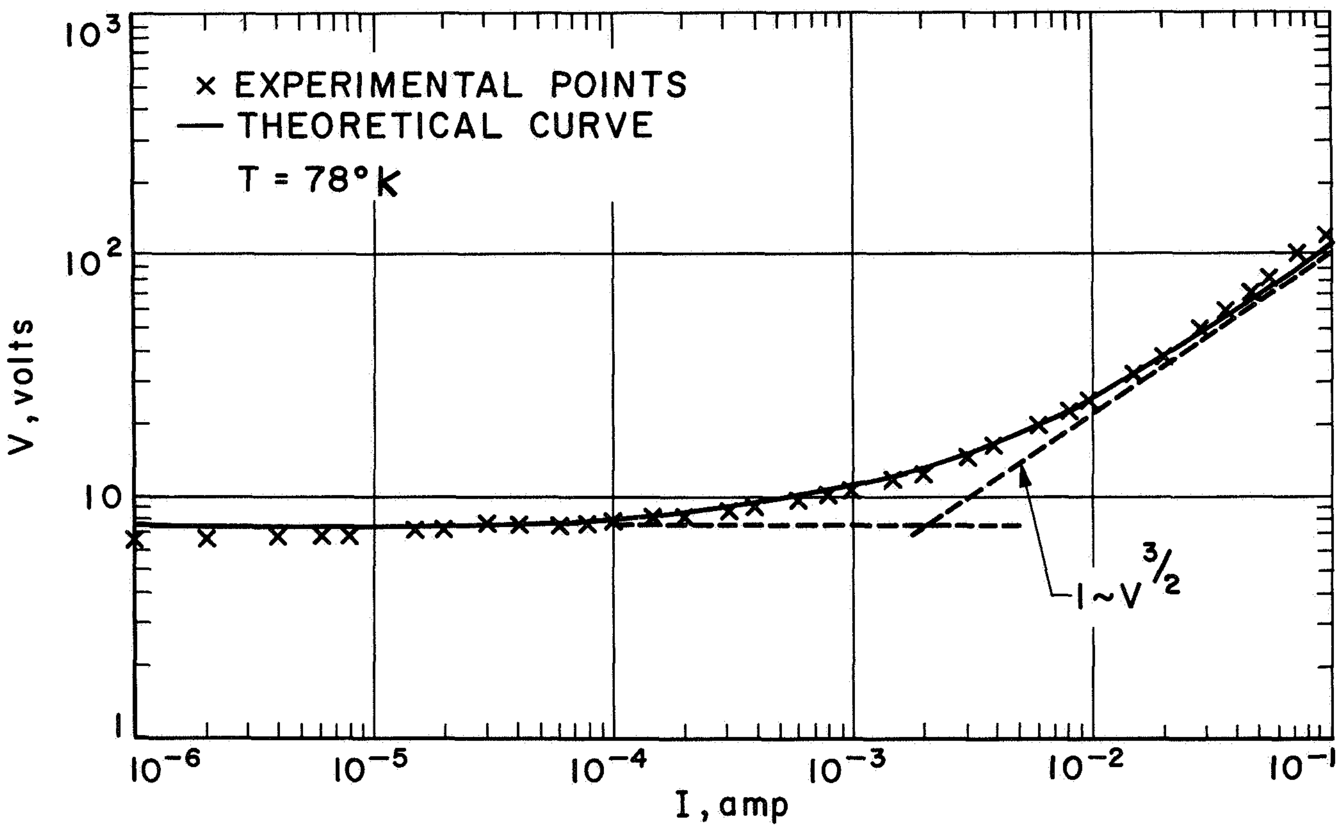
2. Maserjian, J., work performed at CIT for Ph.D. dissertation; to be published.

PUBLICATIONS

1. Shumka, A., Space-Charge-Limited Current in Germanium: Fabrication of Solid State Diodes, p. 64, JPL Space Programs Summary 37-32, Vol. IV.

2. Nicolet, M. A., and Denda, S., Preparation of $n\pi n$ Structures for the Study of Space-Charge-Limited Current in Silicon, JPL Space Programs Summary 37-33, Vol. IV (to be published).

3. Maserjian, J., Titanium Oxide Thin Films, p. 98, JPL Space Programs Summary 37-31, Vol. IV.



A COMPARISON BETWEEN THEORY AND EXPERIMENT FOR SCL CURRENT IN AN $n-\pi-n$ GERMANIUM STRUCTURE AT $T=78°K$ ($W=110\mu$, $A \simeq 3.8 \times 10^{-3} cm^2$ $N_A \simeq 10^{12} cm^{-3}$ AND $V_{pt} = 7.6 v$)

PROGRAM SUMMARY

OART 129

FY'66

NASA TASK NO.	SECTION	TITLE	TOTAL MANPOWER	TOTAL FUNDING
129-01-01-01	326	Molecular Spectroscopy	3.2	152
129-01-09-01	327	Continuum Fluid Dynamics	3.9	201
129-01-10-01	327	Rarefied Gas Dynamics	6.2	221
129-01-05-02	327	Magneto Fluid Dynamics	5.0	185
129-01-05-03	327	Shock Heated Plasmas and Jet Structures	2.2	91
129-02-03-04	326	Quantum Chemistry	1.0	81
129-02-03-02	326	Photochemistry	2.2	119
129-02-03-06	326	Radiation Chemistry	1.2	70
129-02-03-03	327	Plasma Physics	2.3	142
129-02-05-04	328	Low Temperature Physics	2.2	121
129-02-07-02	328	Theoretical Physics	6.0	260
129-02-03-08	328	Nuclear Physics Research	4.0	241
		TOTAL	41.6	2010 1)

NRM:pao

1 man = 1

9-20-65

1) Partially supported by prior year funds

FLUID PHYSICS - DIVISION 32

TITLE NASA Code JPL Code	FISCAL YEAR	PROFESSIONAL MAN-YEARS	DOLLARS (in 000's)
Molecular Spectroscopy			
129-01-01-01	1964	2.0	148
329-10101-1-3260	1965	1.8	118
	1966	1.8	152
Magneto-Fluid Dynamics			
129-01-05-02	1964	2.5	150
329-10801-1-3270	1965	3.2	154
	1966	3.5	185
Shock Heated Plasmas and Jet Structures			
129-01-05-03	1964	Part of 129-01-10-01	
329-11301-1-3270	1965	1.3	69
	1966	1.2	91
Continuum Fluid Dynamics			
129-01-09-01	1964	5.0	373
329-10201-1-3270	1965	3.6	221
	1966	2.7	200
Rarefied Gas Dynamics			
129-01-10-01	1964	5.0	370
329-10501-1-3270	1965	5.0	307
	1966	3.2	220

2. Deutero-derivatives of 2,4-dicarbaclovoheptaborane(7).

(This work was done in collaboration with Prof. R. Beaudet, at U.S.C., and Prof. T. Onak at Cal. State, Los Angeles, California.)

To understand the NMR spectrum of 2,4-dicarbaclovoheptaborane(7), a deuterium exchange reaction was performed. The ^{11}B resonances as observed in the normal molecule are split into doublets. By using ^{1}H substitution, the interpretation of the normal molecule spectrum should be simplified. However, the NMR spectrum of the ^{1}H substituted molecule was itself ambiguous. The difficulties in the NMR assignment were resolved by the study of the microwave spectrum of the deuterated molecule. The microwave results showed that the three ring hydrogen atoms were involved in deuterium substitution, thus providing an unambiguous assignment for the NMR spectrum. These atoms may be found by reference to Figure 1.

3. 2,3-dicarbaclovohexaborane(6). (In collaboration with Prof. Beaudet, at U.S.C.)

Another new compound in the carborane series is shown in Fig. 2. The original data on this compound showed that it had the formula $C_2B_4H_6$, but the skeletal configuration was uncertain. The microwave spectral analysis shows that this molecule is very nearly a spherical top, with a dipole moment of 1.50 D units, again determined by Stark effect measurements. By assigning the spectra for six isotopic boron species, the boron atoms have been located in the molecular principal axis frame. The boron-boron bond distances which are calculated from this information are also shown in Fig. 2. Approximate B-C bond lengths can also be calculated, but because their accuracy is low, they are

Title MOLECULAR SPECTROSCOPY

NASA PROGRAM	SCIENCE TASK LEADER	DIRECTED TOWARD WHICH FLIGHT PROGRAM?
129	R. Poynter S. Trajmar	

BUDGET (K) | NASA Code:129-01-01-01 | JPL Job. No.329-10101-1-3260

	E	T	Total	Salary	Proc.	Total Direct	Total Green
FY '65	2	1	3	33	40	73	118
FY '66	2	1.2	3.2	35	62	97	152

Total FY '66 Commitments to 1 September 1965 32

OBJECTIVE:

Microwave spectroscopy will be used to study molecules and free radicals which are present in planetary atmospheres or in space. The molecular rotational, spin re-orientation and Λ doubling energy levels and transitions involved will be studied.

To design and build a low-energy, high-resolution electron impact spectrometer. To obtain data with this instrument on energy levels and transitions in atomic and molecular targets and to determine cross sections for elastic and inelastic processes involving low-energy electrons and atoms (molecules).

ABSTRACT:

1. 2,4-dicarbaclovoheptaborane(7). (In collaboration with Prof. R. Beaudet, at U.S.C.)

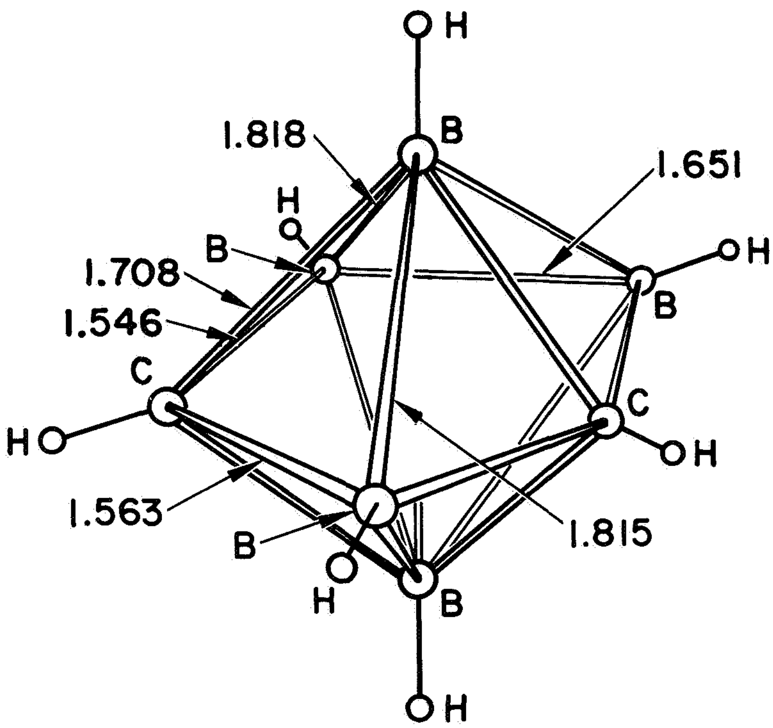
The study of this molecule has been completed and a final report has been published in the Journal of Chemical Physics. The final results on this molecule are briefly summarized. The skeletal carbon-boron cage structure of this molecule is shown in Figure 1, along with the bond lengths obtained from this study. The molecular dipole moment is 1.32 D units, as determined by measurements of the Stark effect. An adequate theoretical explanation of the unusual bonding found in this molecule is not known at this time.

shown enclosed in parentheses in Fig. 2. The study of the ^{13}C isotopic species which has not been analyzed at this time will accurately determine the carbon atom locations and the B-C bond lengths. This will complete the study of this molecule.

4. Free Radical Studies. (In collaboration with Prof. R. Beaudet at U.S.C.)

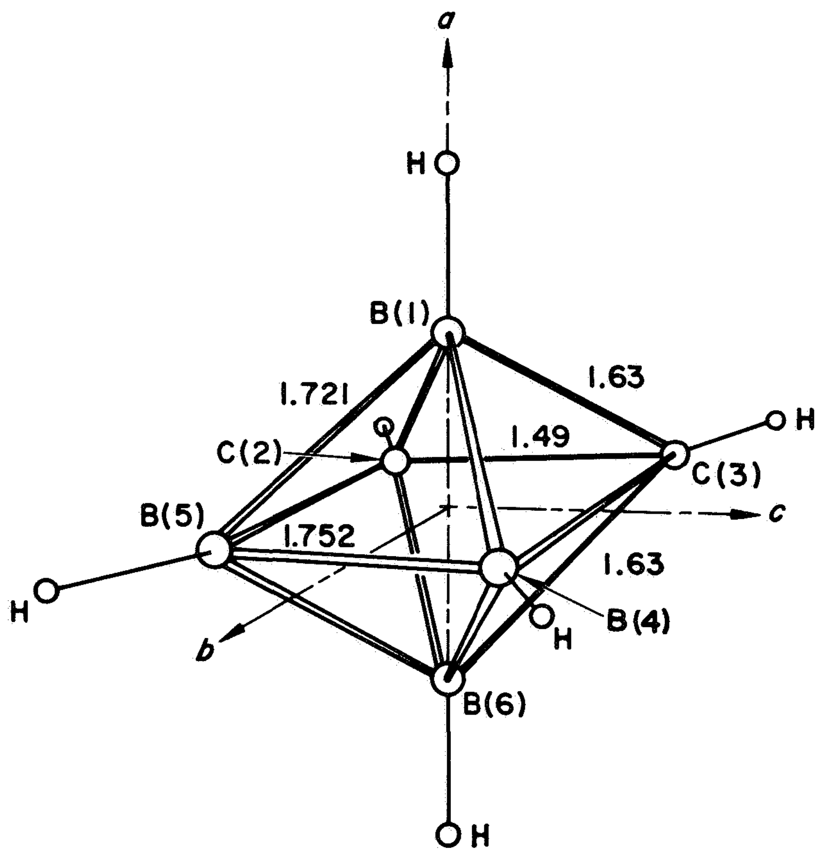
During this period an absorption cell suitable for the microwave spectroscopy of gaseous free radicals has been designed and is being constructed. The absorption cell plate waveguide, the vacuum tank and support, and the main vacuum pump have been obtained. The microwave transitions, and the ultra-high vacuum pump have been ordered and will be delivered this month or next month. A residual gas analyzer is being incorporated into the experimental system both to assist with the expected vacuum problems and to act as a monitor to the experimental parameters in the course of operation.

MOLECULAR SPECTROSCOPY



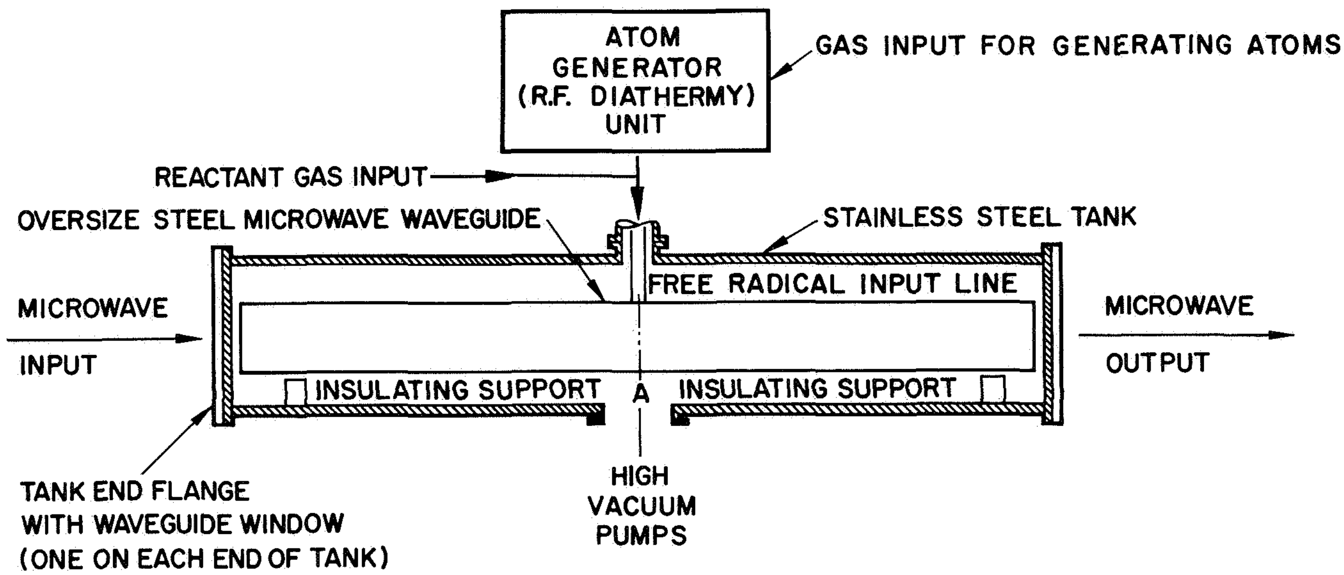
MOLECULAR CONFIGURATION AND BOND DISTANCES IN
2,4-DICARBACLOVOHEPTABORANE (7)

MOLECULAR SPECTROSCOPY



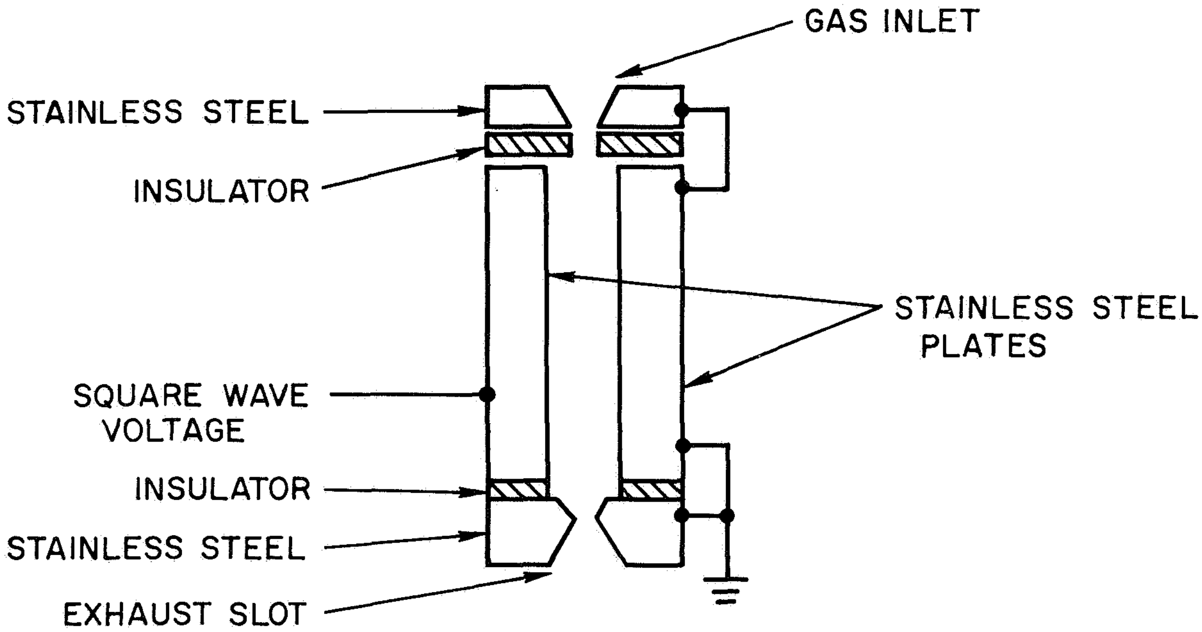
ATOMIC CONFIGURATION AND BOND DISTANCES IN 2,3-DICARBACLOVOHEXABORANE (6). PRINCIPAL AXES FOR THE ALL ^{11}B ISOTOPIC SPECIES ARE SHOWN BY THE ARROWS

MOLECULAR SPECTROSCOPY



FREE RADICAL MICROWAVE ABSORPTION CELL

MOLECULAR SPECTROSCOPY



CROSS SECTION (A–A) OF ABSORPTION CELL PLATES

Title: LOW-ENERGY ELECTRON IMPACT SPECTROMETRY

ABSTRACT:

Recent development in high-vacuum techniques and in particle detector and energy analyzer systems make it feasible to build a low-energy, high-resolution electron impact spectrometer for the purpose of obtaining a great variety of data. One can obtain information on energy levels and on transitions between energy states of atomic and molecular targets and on cross sections for elastic and inelastic processes involving low-energy electrons and atoms and molecules.

This type of data is needed for quantitative calculations in atmospheric and solar physics, in connection with plasma and discharge phenomena, in spectroscopy in chemistry and for guiding theoretical work.

The design and construction of a low-energy, high resolution electron scattering apparatus was initiated in September, 1964. The Model I instrument is being built in cooperation with Prof. Aron Kuppermann and Mr. James Rice (C.I.T.).

All the design work for Model I instrument is now complete. The bakeable high-vacuum system, furnace, sample handling system, pressure measuring and calibration system, electromagnetic shielding and compensation, electron gun, energy selector, scattering chamber, electron detector system and all associated electronic components are built and purchased. The mounting, the assembly and testing of the instrument is in progress. The schematic diagram of the apparatus is shown on Figure I.

The electron gun forms an intense, well collimated beam which is then decelerated and energy selected at 2 eV kinetic energy by the spherical electrostatic deflector. The equation of motion can be rigorously solved for these selectors. Trajectories and electro-optical aberrations of the system have been calculated. The nearly

monoenergetic beam ($\Delta E = 0.020$ eV) leaving the energy selector is then reaccelerated and focused into the scattering chamber. Electrons which scattered into a specific direction are reaccelerated by a sweep voltage, V_1. Those electrons that last V_1 eV energy will regain the last energy, return to the initial trajectory and will be transmitted through the analyzer into the collector. A sweep voltage can also be applied to the cathode to change the energy of the incoming electron. The sweep voltages are obtained either from the counting system in steps (where the voltage at each step is proportional to the channel number into which the counts are being accumulated) or by a sweep circuitry which changes the voltage continuously with time.

The scattering chamber is shown on Figure II. It is a double bellows system with temperature control (-180°C to $+ 300^{\circ}$C) and capable of a -30° to $+ 90^{\circ}$ bent.

Special care has been taken to shield and compensate against electromagnetic disturbances and to measure pressure with an accuracy of $\pm$ 5%.

When current levels are high, a vibrating reed electrometer and an X-Y recorder will be used for recording the spectrum. At low signal levels counting techniques will be applied. A Nuclear Data 1024 channel scaler system has been modified to our specifications. It supplies analog voltages for the energy loss sweep and for chopping the electron beam. In the first 512 channels of the memory the signal counts and in the second 512 channels of the memory the background counts will be alternatingly collected.

There are three types of experiments which can be done with the Model I apparatus:

A. Energy loss spectrum

B. Resonances in the electron transmission and in differential elastic cross sections

C. Angular spectrum

Type A spectrum is shown on Figure III (from Simpson), Type B curves are shown on Figure IV and V (from Simpson and Schulz respectively).

In Model II apparatus the scattering chamber will be slightly modified and instead of the scattered electrons the photons emitted by the excited species will be studied. Electron excitation and optical observation combine the advantages of electron impact and optical spectroscopy, namely, excitation to any level with high resolution. Additional information in the form of the polarization of the emitted radiation can be obtained. Polarization of the radiation and the angular distribution of the emitted photons will be studied. Besides the type of information obtainable from studying the scattered electrons (energy levels and cross sections) this method yields important information on energy transfer by collision.

The instrument has been designed with flexibility in mind and it can be easily modified. It is planned for the future to replace the static sample with molecular beam. This will make possible the study of free radicals and provide a better definition of scattering volume. Mass analysis of the beam with a quadrupole mass filter will also be possible.

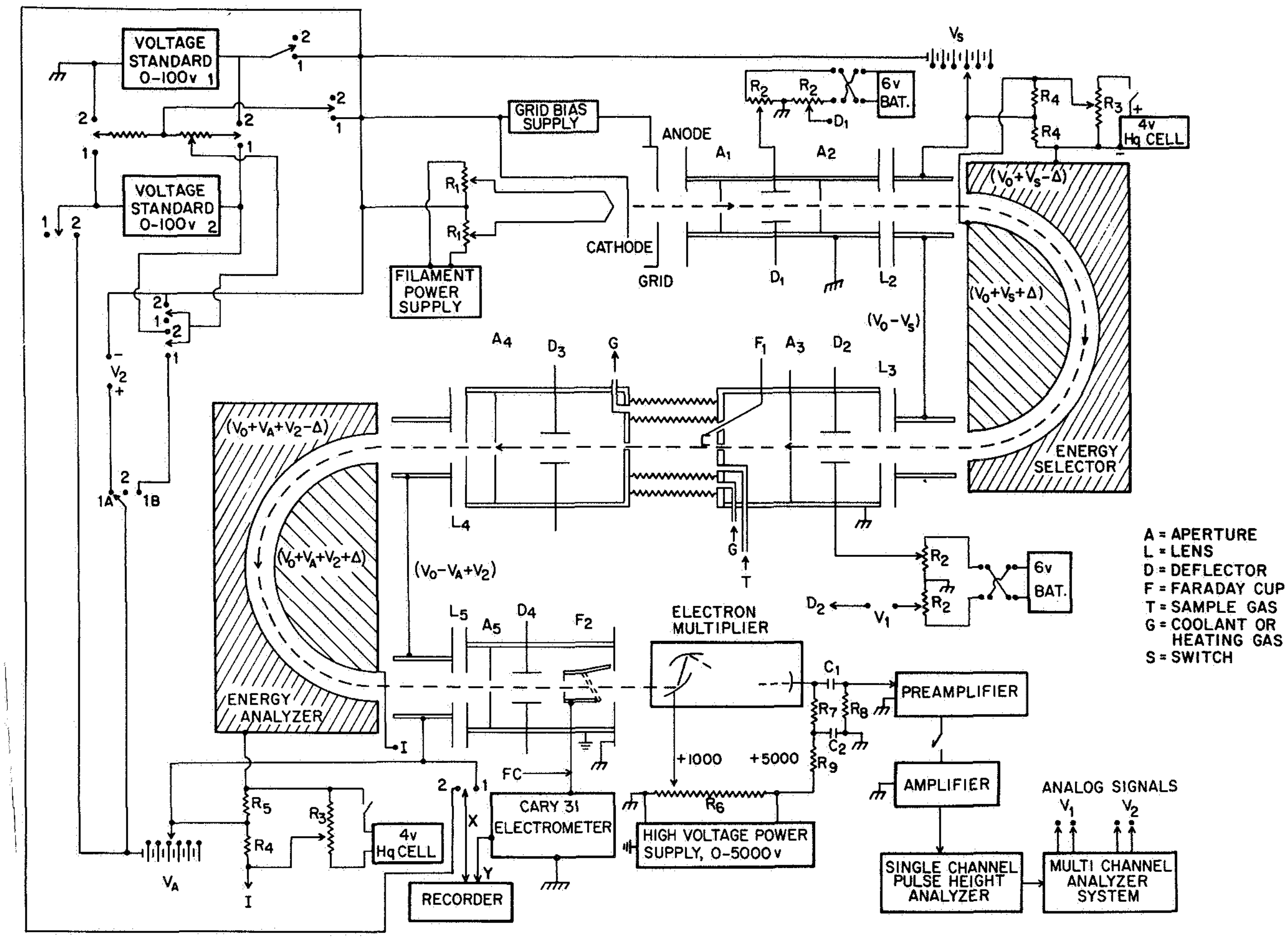
Plans

Complete the construction of the apparatus, assemble and test apparatus.

Publications

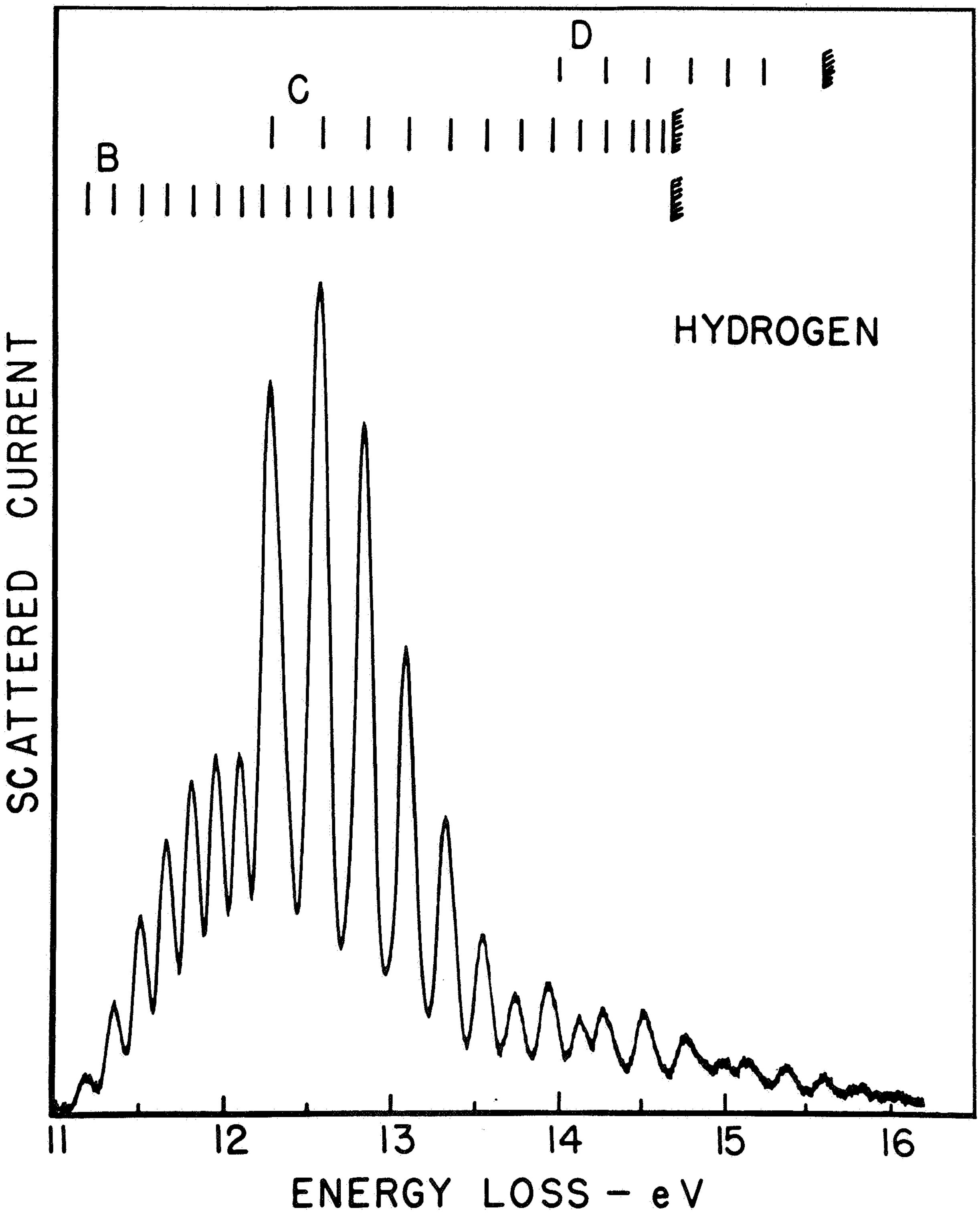
A paper on induced infrared spectra in liquid rare gases by George Ewing, Sandor Trajmar and G. Holleman has been presented by one of us at the European Molecular Spectroscopy Meeting in Copenhagen (August, 1965).

MOLECULAR SPECTROSCOPY



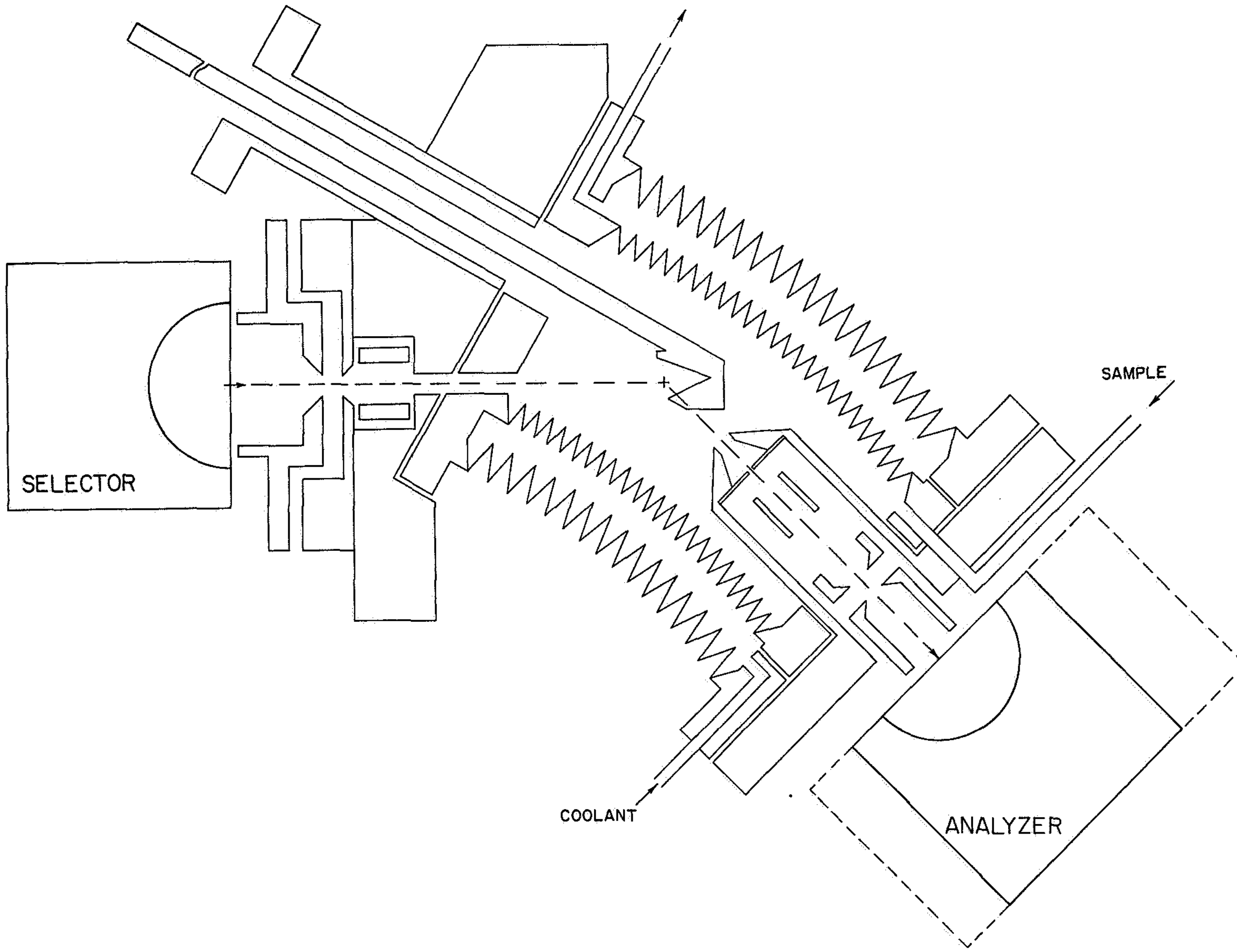
SCHEMATIC DIAGRAM OF ELECTRON IMPACT SPECTROMETER

MOLECULAR SPECTROSCOPY



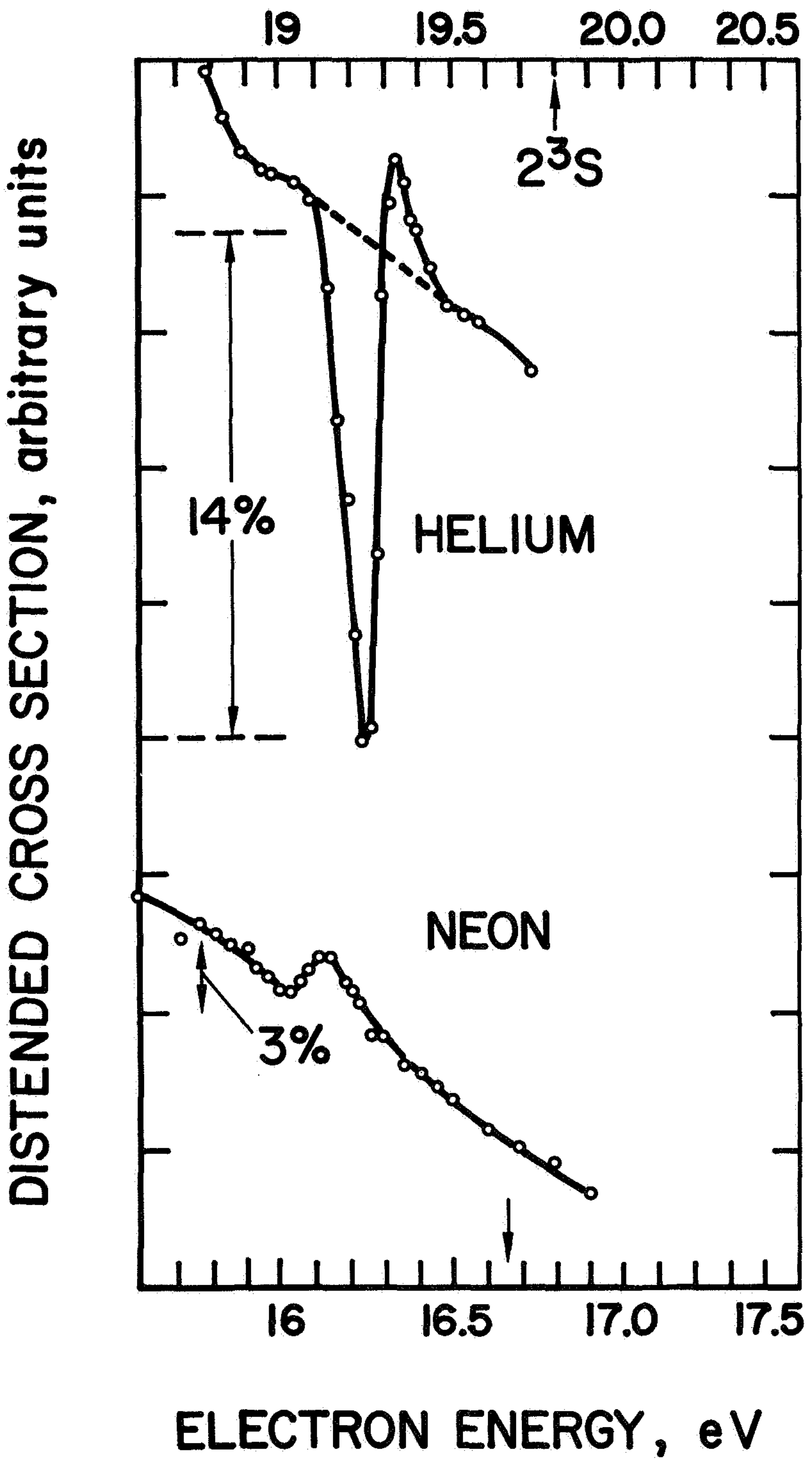
ELECTRON IMPACT
SPECTRUM OF HYDROGEN

MOLECULAR SPECTROSCOPY



SCATTERING CHAMBER

MOLECULAR SPECTROSCOPY



ENERGY DEPENDENCE OF THE ELASTIC CROSS SECTION AT AN ANGLE OF 72 deg IN HELIUM AND NEON

Title Continuum Fluid Dynamics

NASA PROGRAM	SCIENCE TASK LEADER	DIRECTED TOWARD WHICH FLIGHT PROGRAM?
129	Dr. J. M. Kendall, Jr.	

BUDGET (K) NASA Code: 129-01-09-01-55 JPL Job. No. 329-10201-1-3270

	E	T	Total	Salary	Proc.	Total Direct	Total Green
FY '65	3.6	0	3.6	51	105	156	221
FY '66	3.4	0.5	3.9	50	72	122	201

Total FY '66 Commitments to 1 September 1965 29

OBJECTIVE:

Theoretical and experimental research on the flow of viscous and compressible fluids. The problems are mostly related to the complex phenomenon of turbulence in a variety of fluids and various flow configurations. They are chosen for their intrinsic interest, for geo- or astrophysical implications, or to exploit the unique capabilities and facilities of this group.

ABSTRACT:

Supersonic Wake Stability and Transition Experiments

Measurement of the stability of the two-dimensional wake flow at Mach 3.7 shown in Fig. 1 has been completed. The amplification rate and propagation speed of artificial disturbances of controlled frequency and amplitude were determined. Excellent agreement with inviscid theory has been obtained, Fig. 2. The astonishing effectiveness of sound radiated from a turbulent boundary layer in promoting wake transition, Fig. 3, has not been explained. Experiments with the three-dimensional artificial disturbances shown in Fig. 4 have failed to clarify this result.

ABSTRACT (CONT.): Continuum Fluid Dynamics

An experimental study of compressible boundary layer stability using experimental techniques developed for the above has been initiated. Multiple instability modes and wave obliqueness effects described below will be studied.

Compressible Boundary Layer Stability Theory

The study of the effect of wall cooling on the inviscid stability of the laminar boundary layer has been extended to higher Mach numbers. Figures 5 and 6 show, as was found previously at $M_1 = 5.8$, that cooling the wall at $M_1 = 8$ and 10 stabilizes the first mode, destabilizes the second and higher modes, and shifts the unstable regions to higher frequencies. At $M_1 = 10$ it is no longer possible to completely stabilize the first mode by cooling.

Previously, the investigation has been limited to the study of two-dimensional disturbances. The inviscid theory has now been applied to oblique waves. In Fig. 7 the maximum amplification rates for the first and second modes are given as functions of the wave angle for four Mach numbers. Obliqueness destabilizes the first mode and stabilizes the second mode. The most unstable disturbance is still the second-mode two-dimensional disturbance.

Experimental Investigations of the Base-Flow Problem

Measurements of the flow behind a wedge with and without a splitter plate, Fig. 8, are being made at Mach numbers between 2.0 and 4.5 in the Reynolds number range $0.2 \sim 2.0 \times 10^6$ based on wedge pressure and length.

ABSTRACT (CONT.): Continuum Fluid Dynamics

Conclusions obtained thus far are:

1. The lip shock-recompression shock pattern changes appreciably with Mach number and Reynolds number, Fig. 9.

2. The pressure-recovery distribution accordingly demonstrates a variety of patterns, Fig. 10.

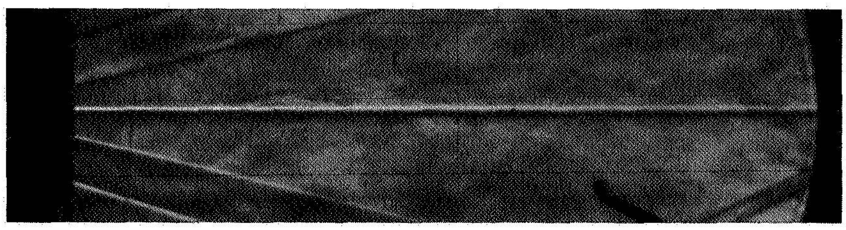
3. The base pressure of the wedge without the splitter plate is usually lower than with the splitter plate, Fig. 11.

4. The strength of the lip shock is estimated to be quite substantial, Fig. 12. This means that the flow around the separation edge overexpands appreciably before it is recompressed to the base pressure through the lip shock.

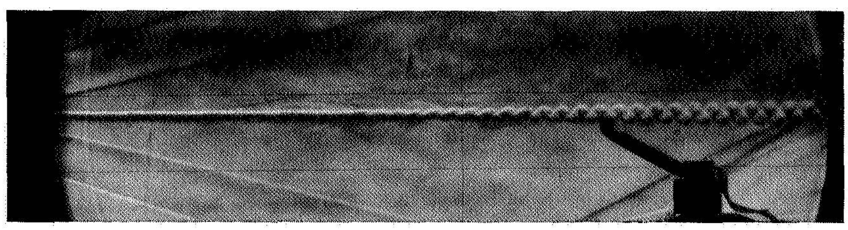
5. At higher Mach numbers, the surface pressure on the base face drops sharply immediately behind the separation edge, Fig. 13, suggesting that the flow might turn the sharp corner before separation from the base face.

Since most of the existing theories of the base-pressure problem do not take account of these experimental facts, particularly the last two, a reconsideration seems necessary.

CONTINUUM FLUID DYNAMICS



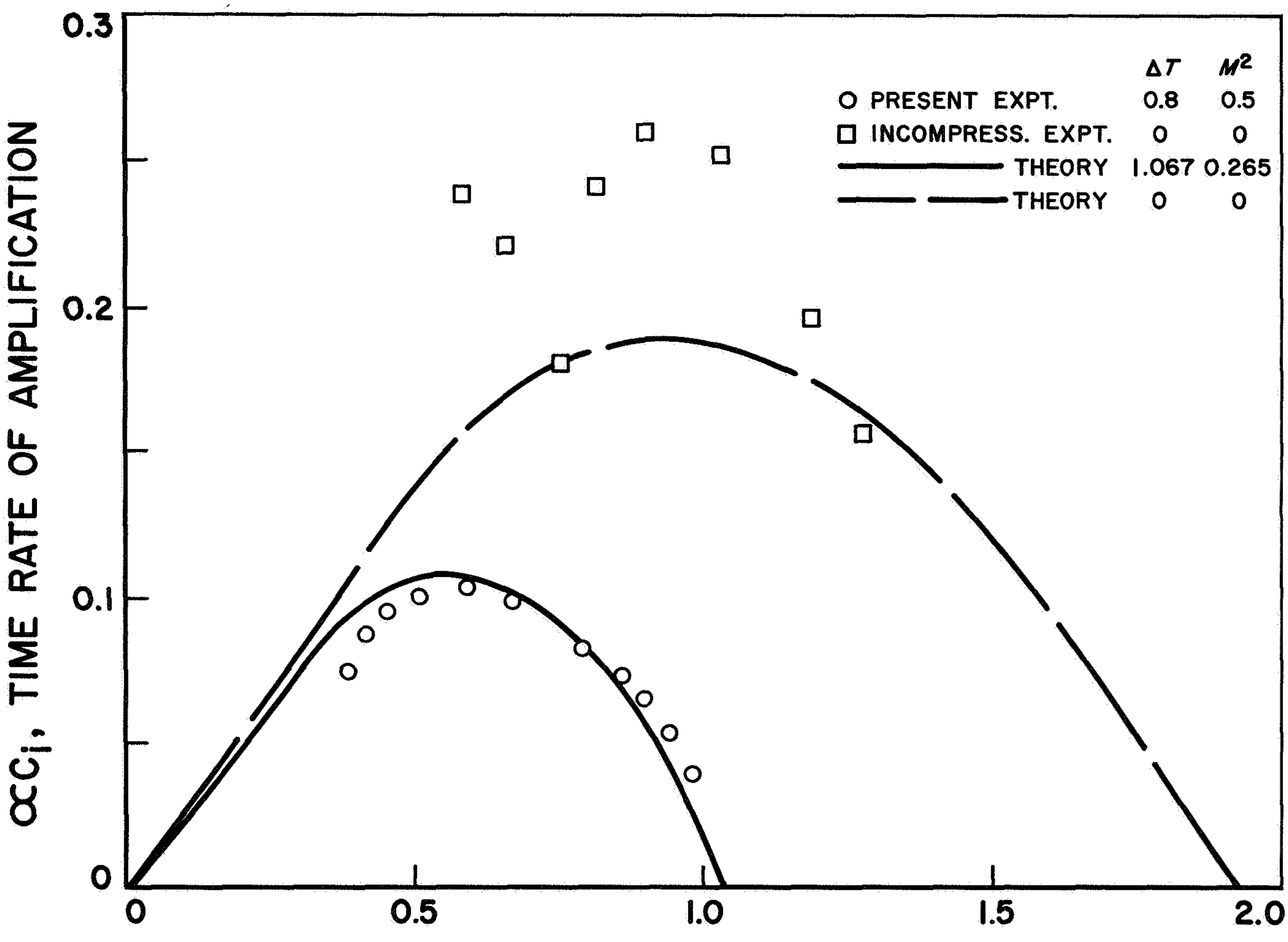
(a) NO DISTURBANCE



(b) PERIODIC DISTURBANCE

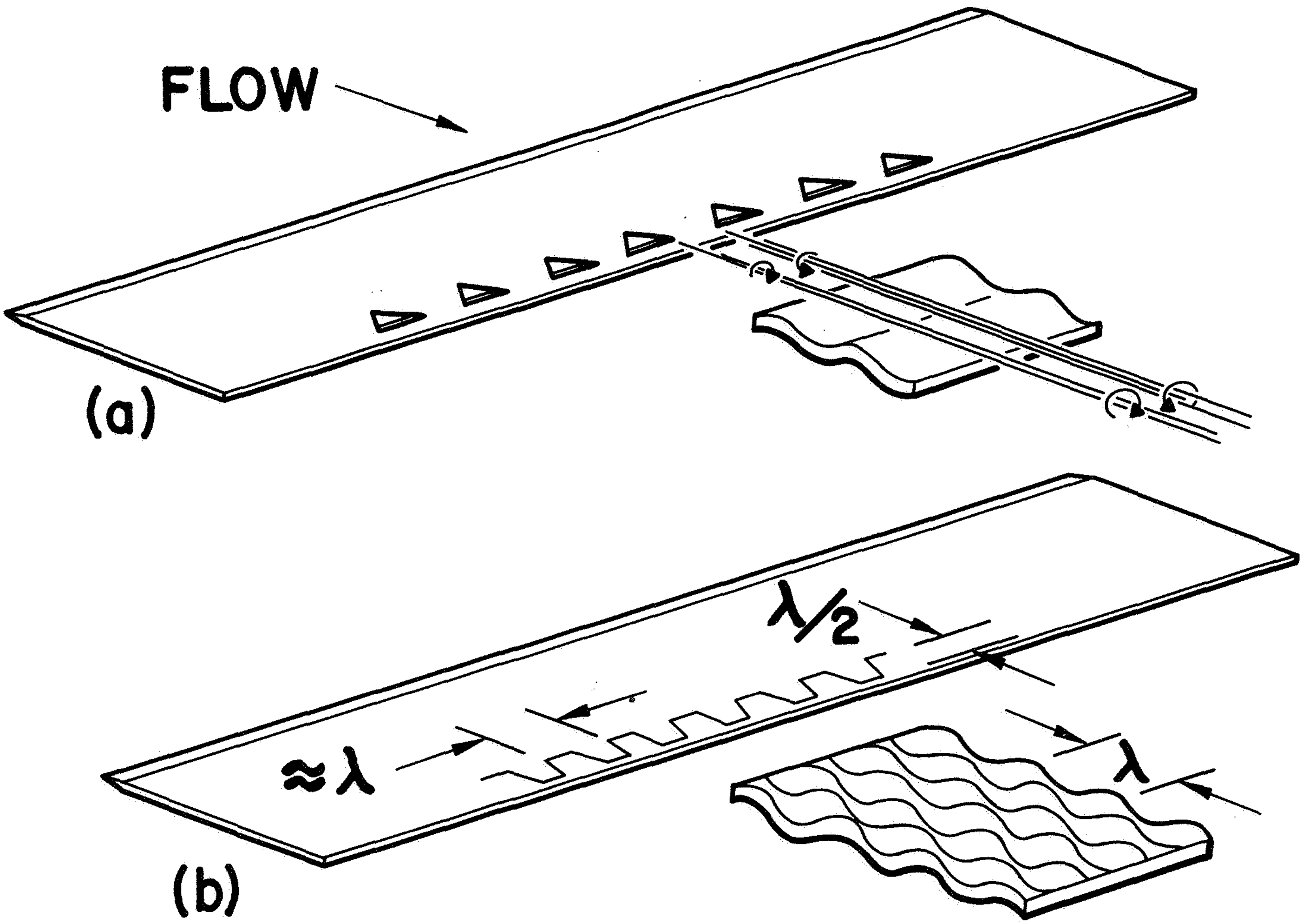
TWO-DIM. WAKE FLOW, $M_\infty = 3.7$

CONTINUUM FLUID DYNAMICS



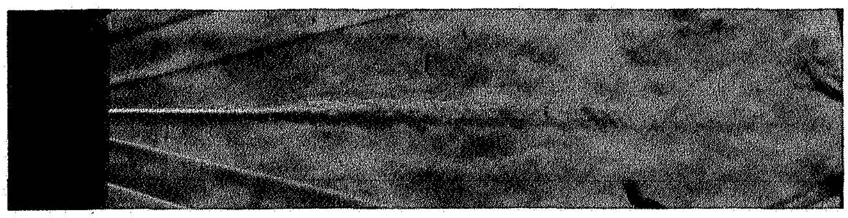
TWO-DIMENSION WAKE STABILITY, $M_\infty = 3.7$

CONTINUUM FLUID DYNAMICS

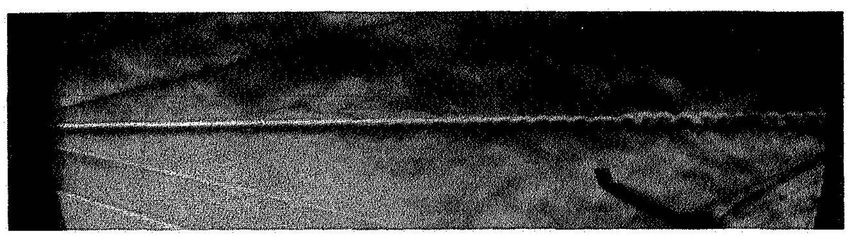


3-DIM. WAKE DISTURBANCES

CONTINUUM FLUID DYNAMICS



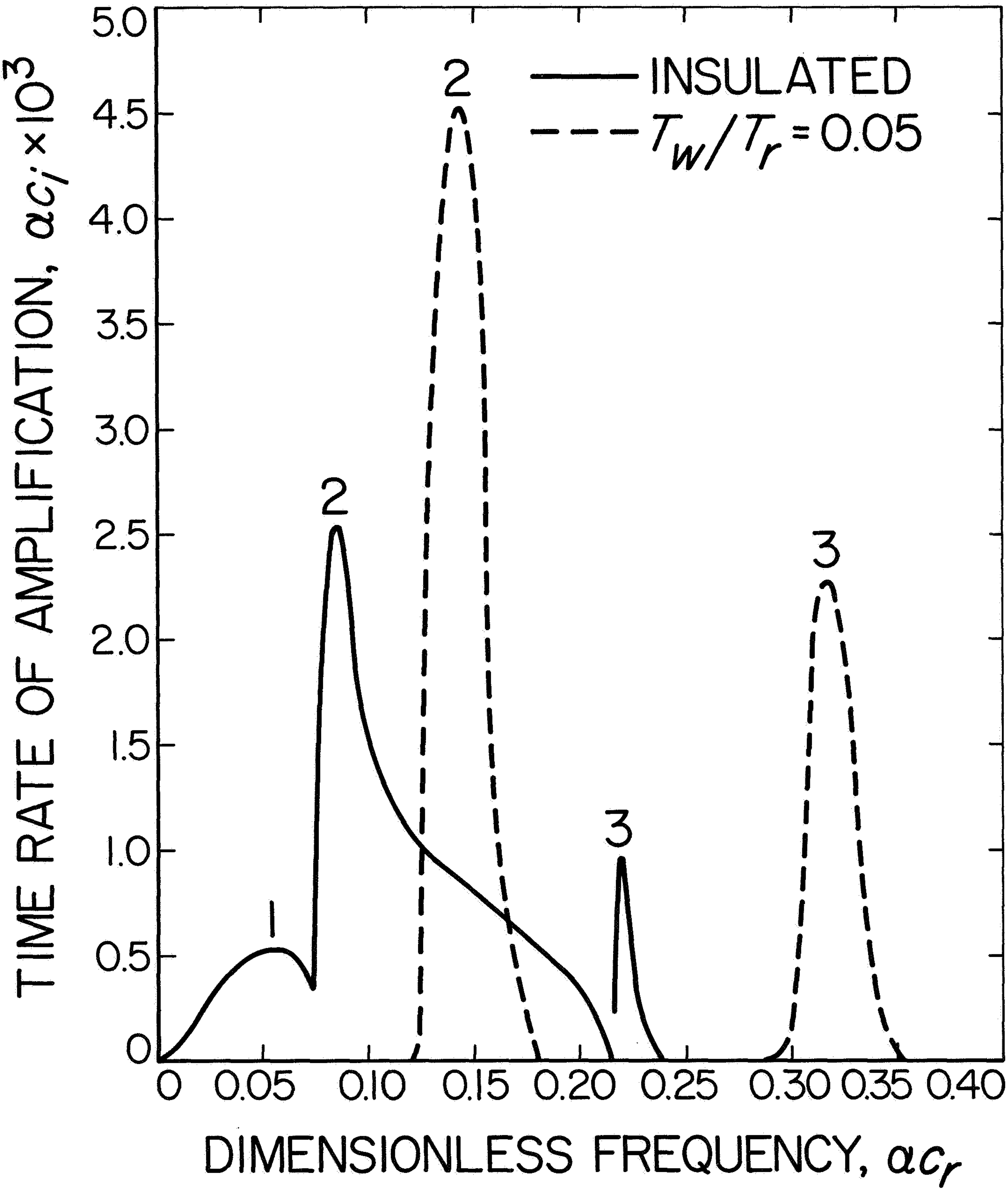
(a) WITH B.L. SOUND



(b) TWO-DIM. WHITE NOISE

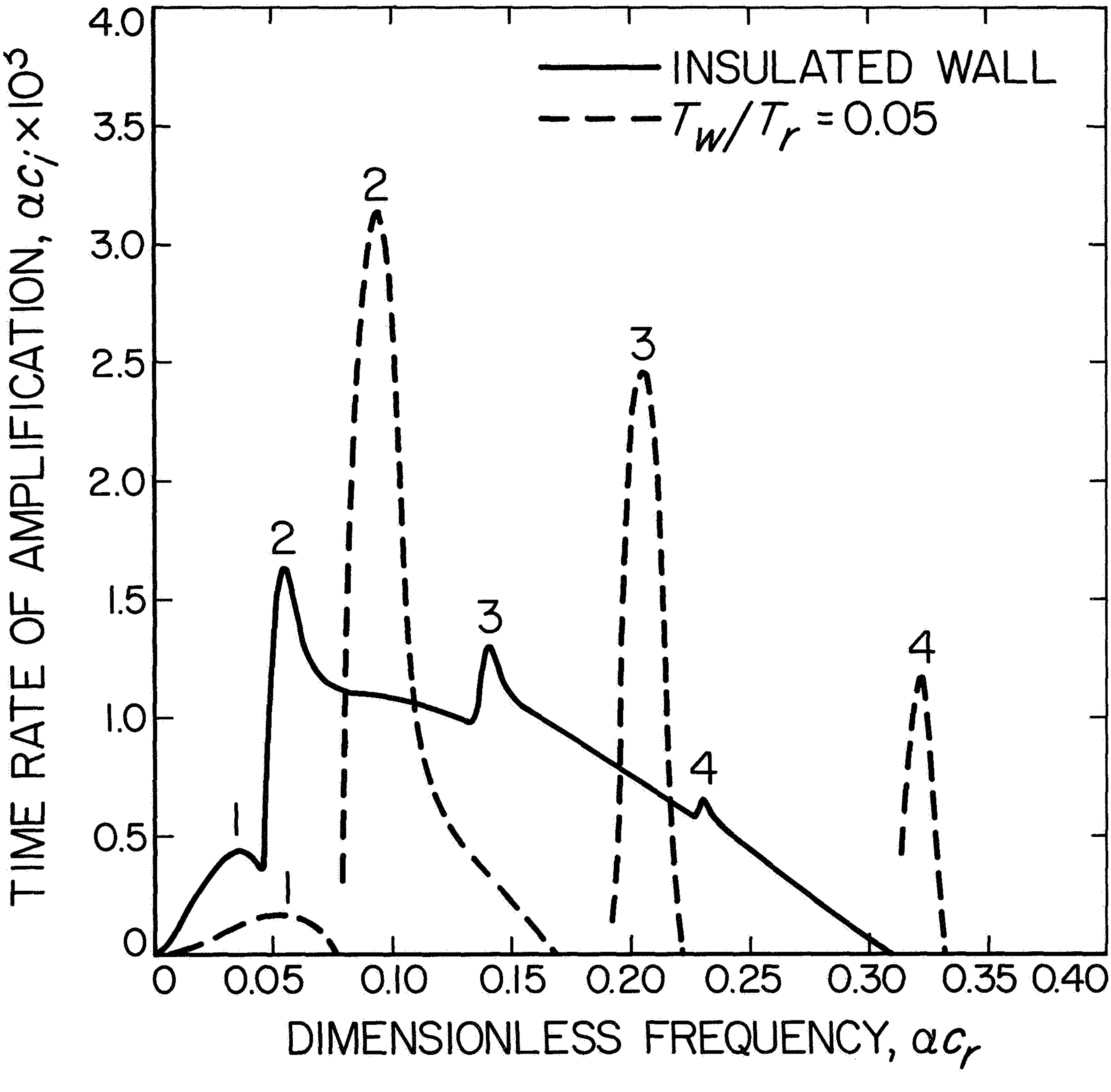
TWO-DIM. WAKE FLOW, $M_\infty = 3.7$

CONTINUUM FLUID DYNAMICS



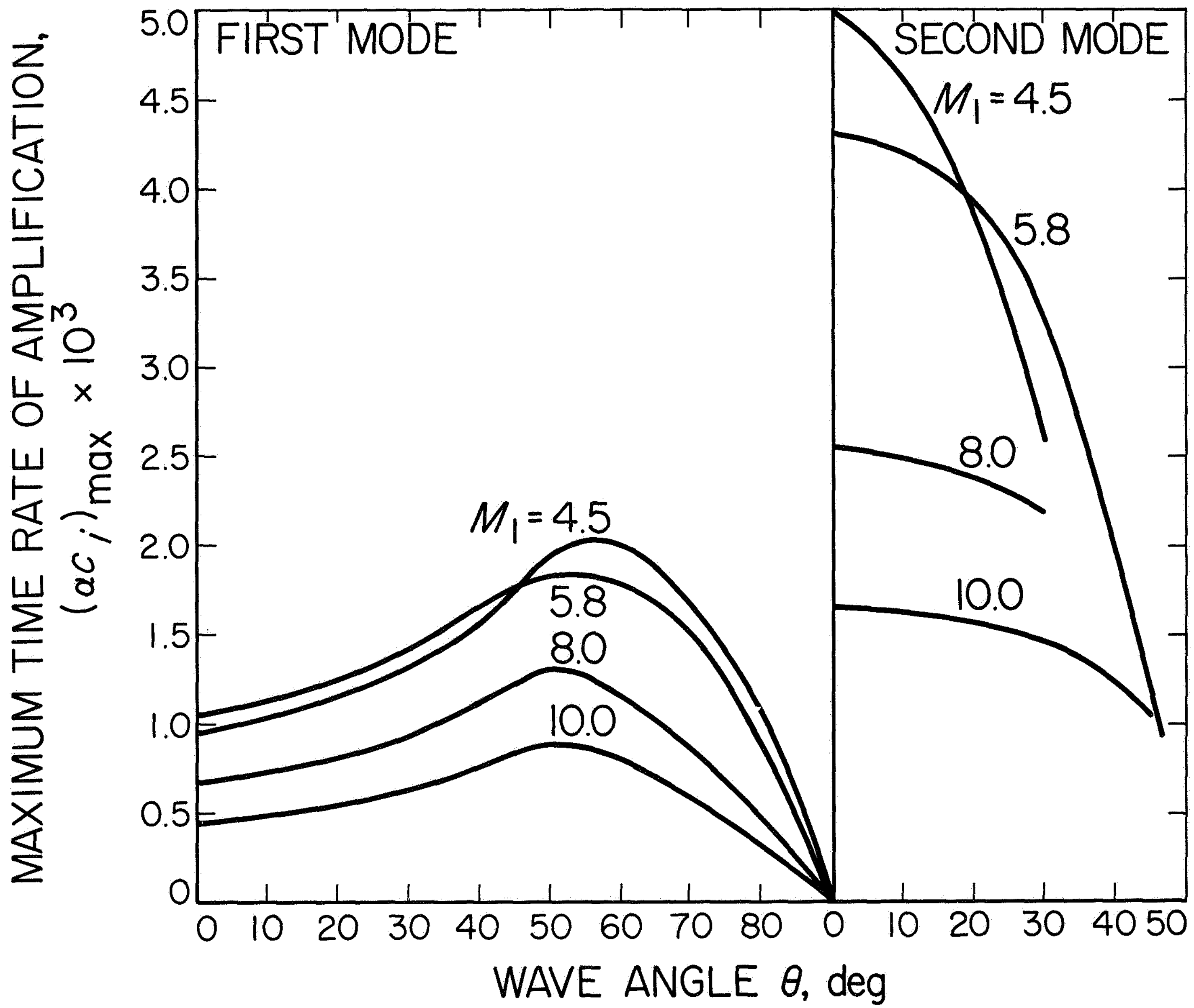
INVISCID AMPLIFICATION RATE
vs FREQUENCY AT $M_1 = 8.0$

CONTINUUM FLUID DYNAMICS



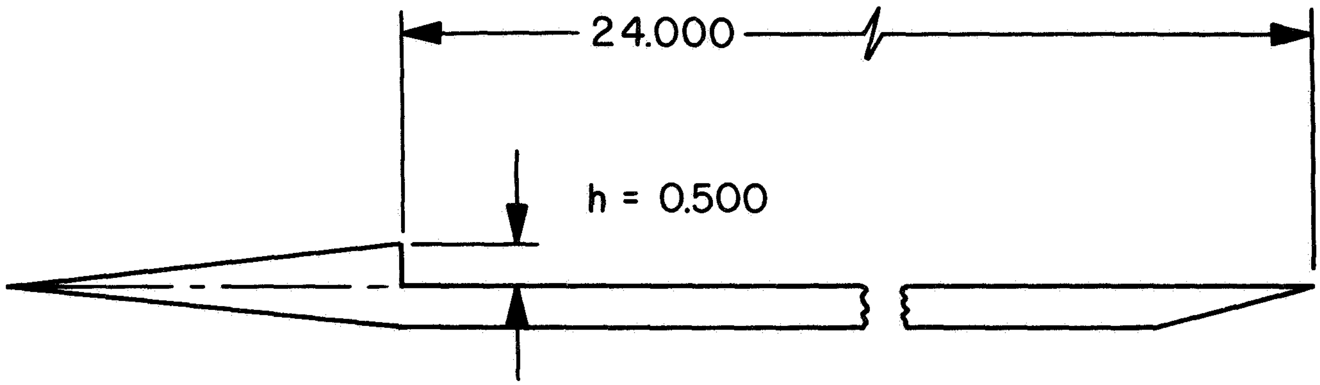
INVISCID AMPLIFICATION RATE
vs FREQUENCY AT $M_1 = 10.0$

CONTINUUM FLUID DYNAMICS

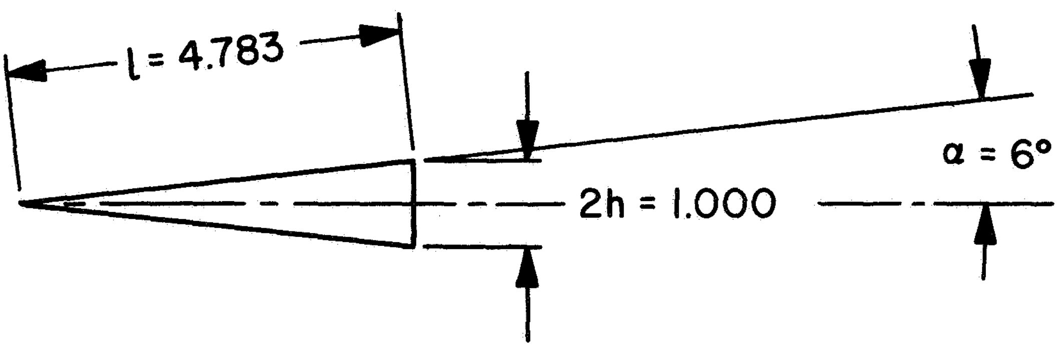


EFFECT OF WAVE ANGLE ON INVISCID AMPLIFICATION RATE

CONTINUUM FLUID DYNAMICS



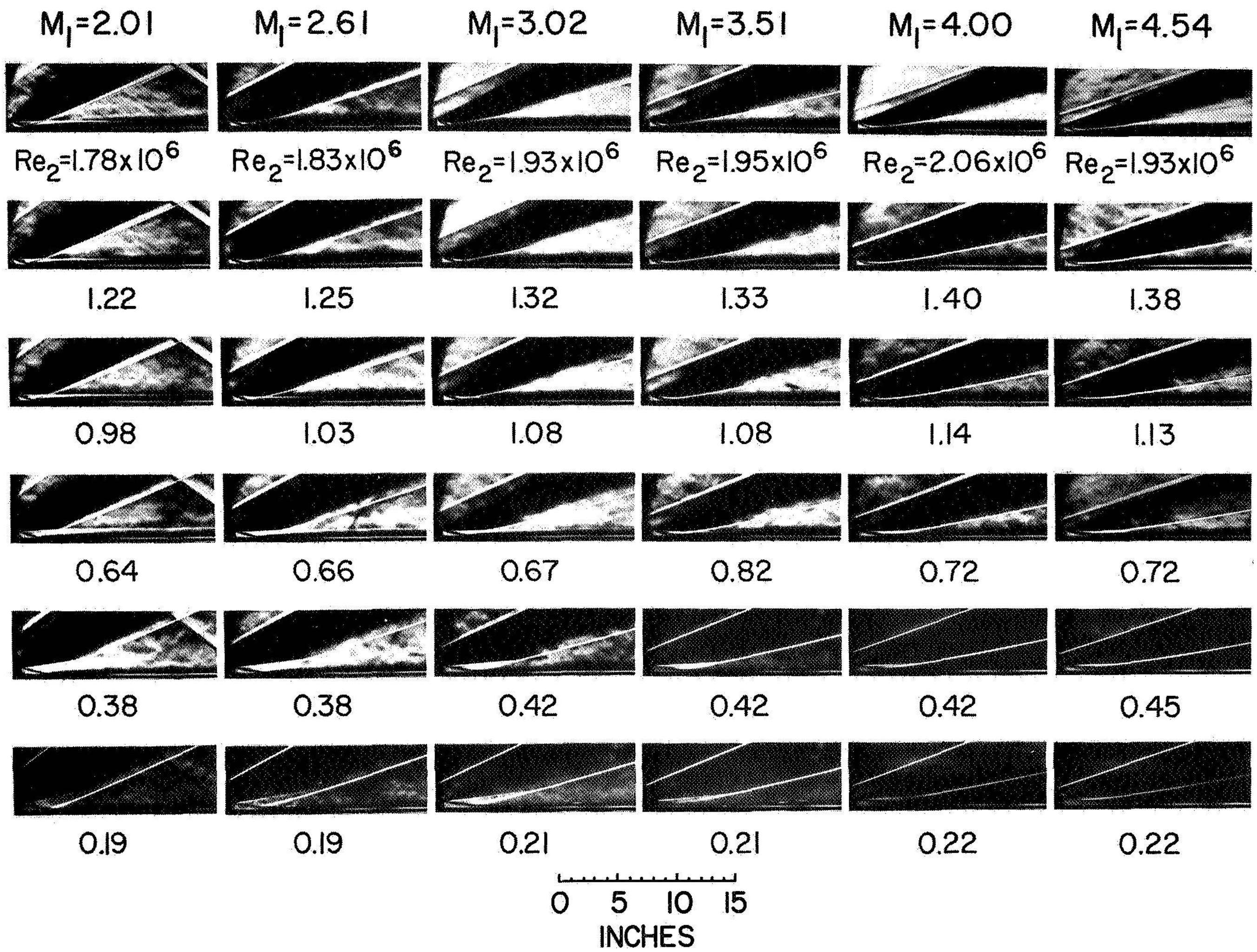
(a) WEDGE WITH SPLITTER PLATE



(b) WEDGE

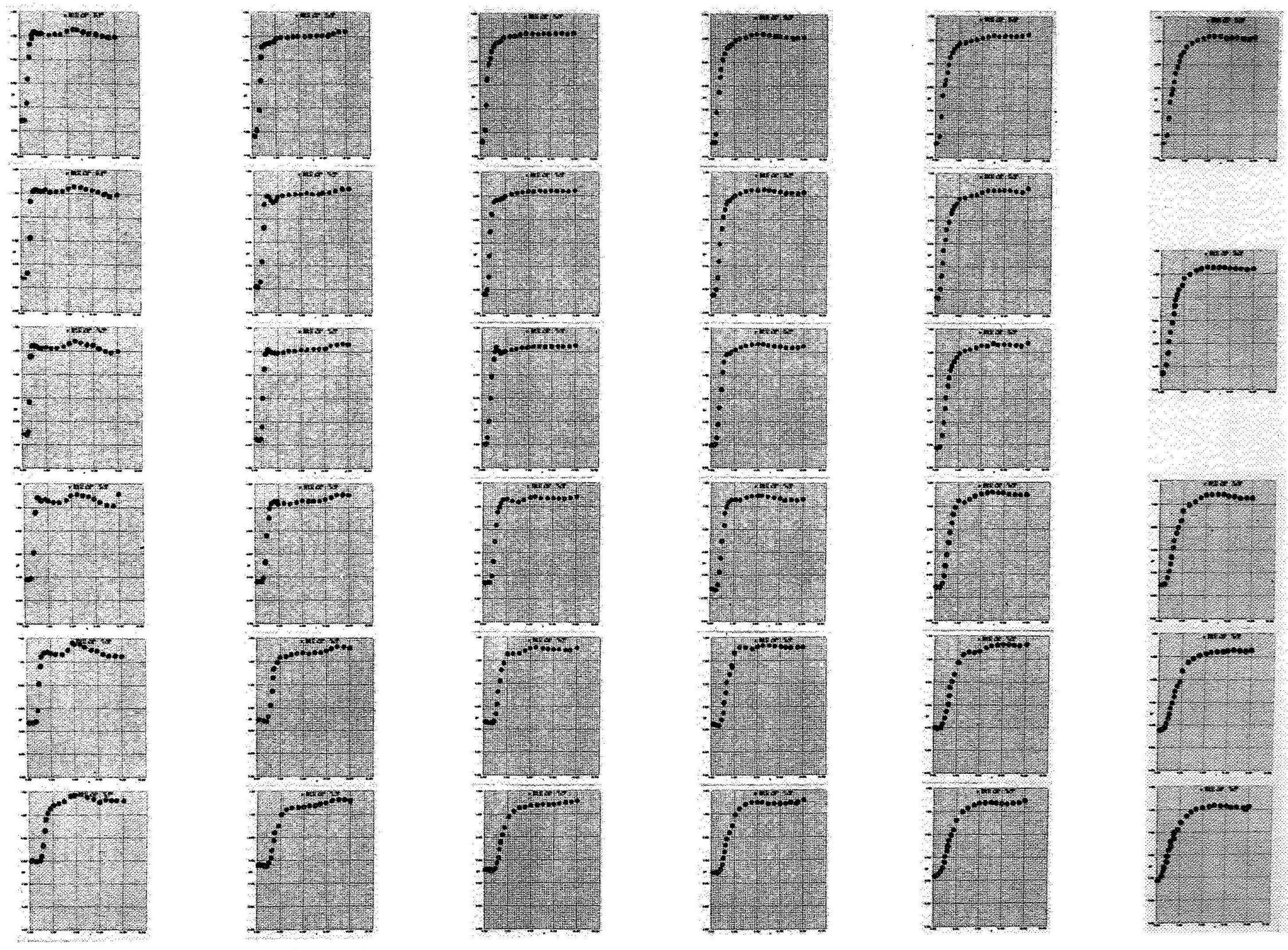
TEST MODELS

CONTINUUM FLUID DYNAMICS



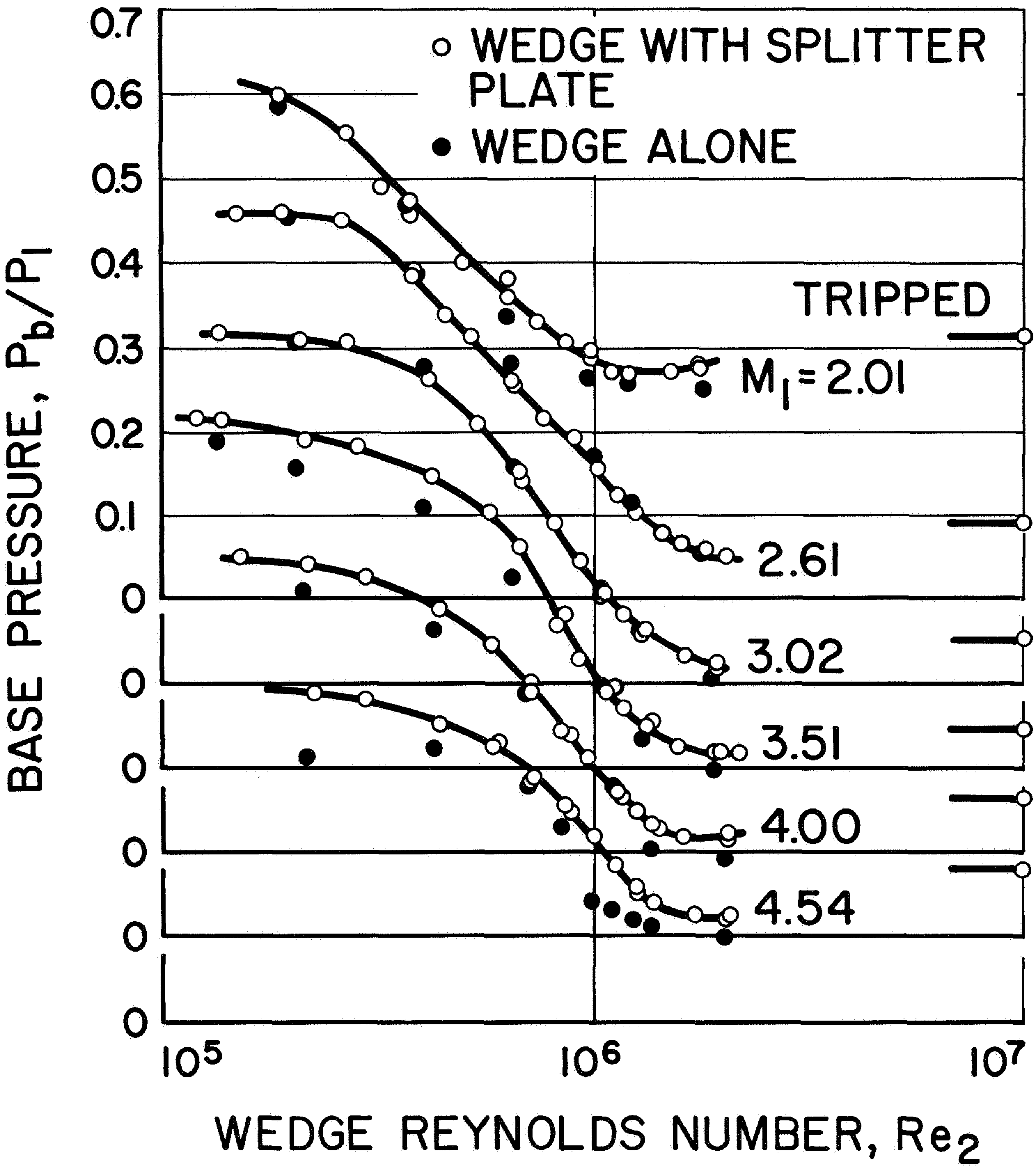
SHOCK PATTERNS BEHIND BACKWARD-FACING STEP

CONTINUUM FLUID DYNAMICS



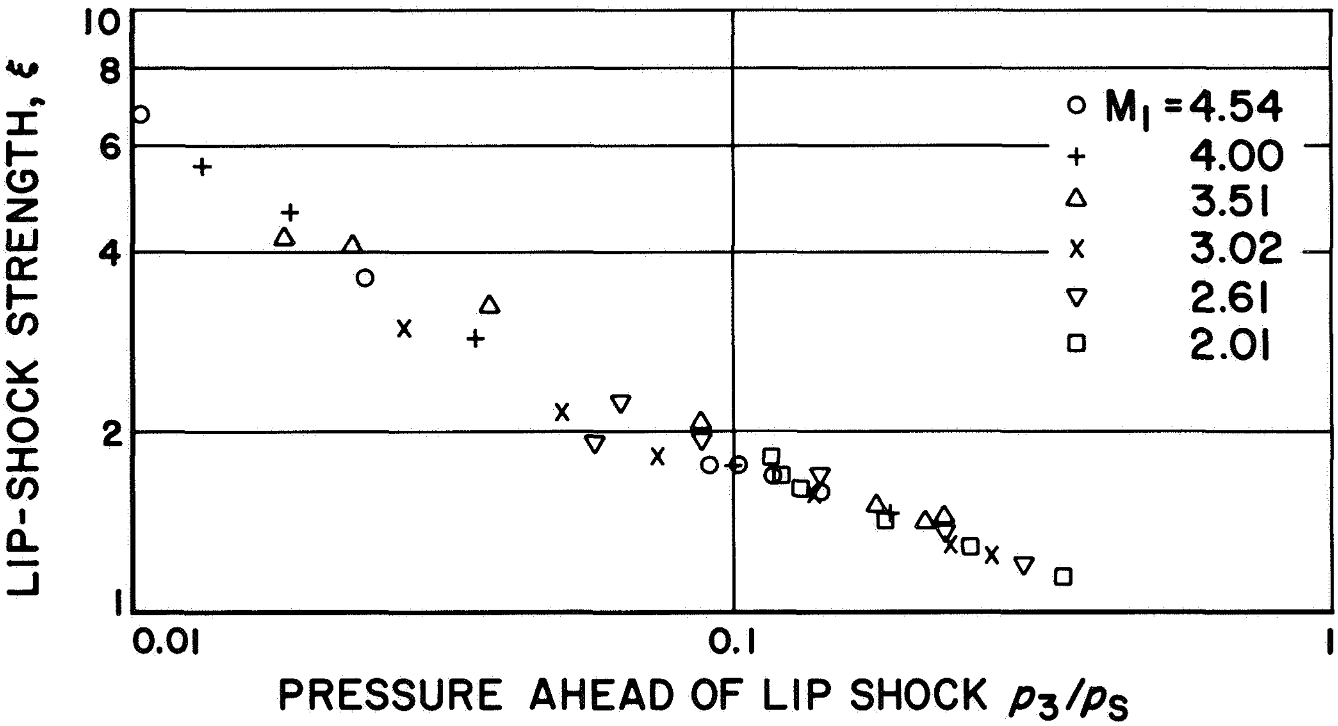
PRESSURE DISTRIBUTION BEHIND BACKWARD-FACING STEP

CONTINUUM FLUID DYNAMICS



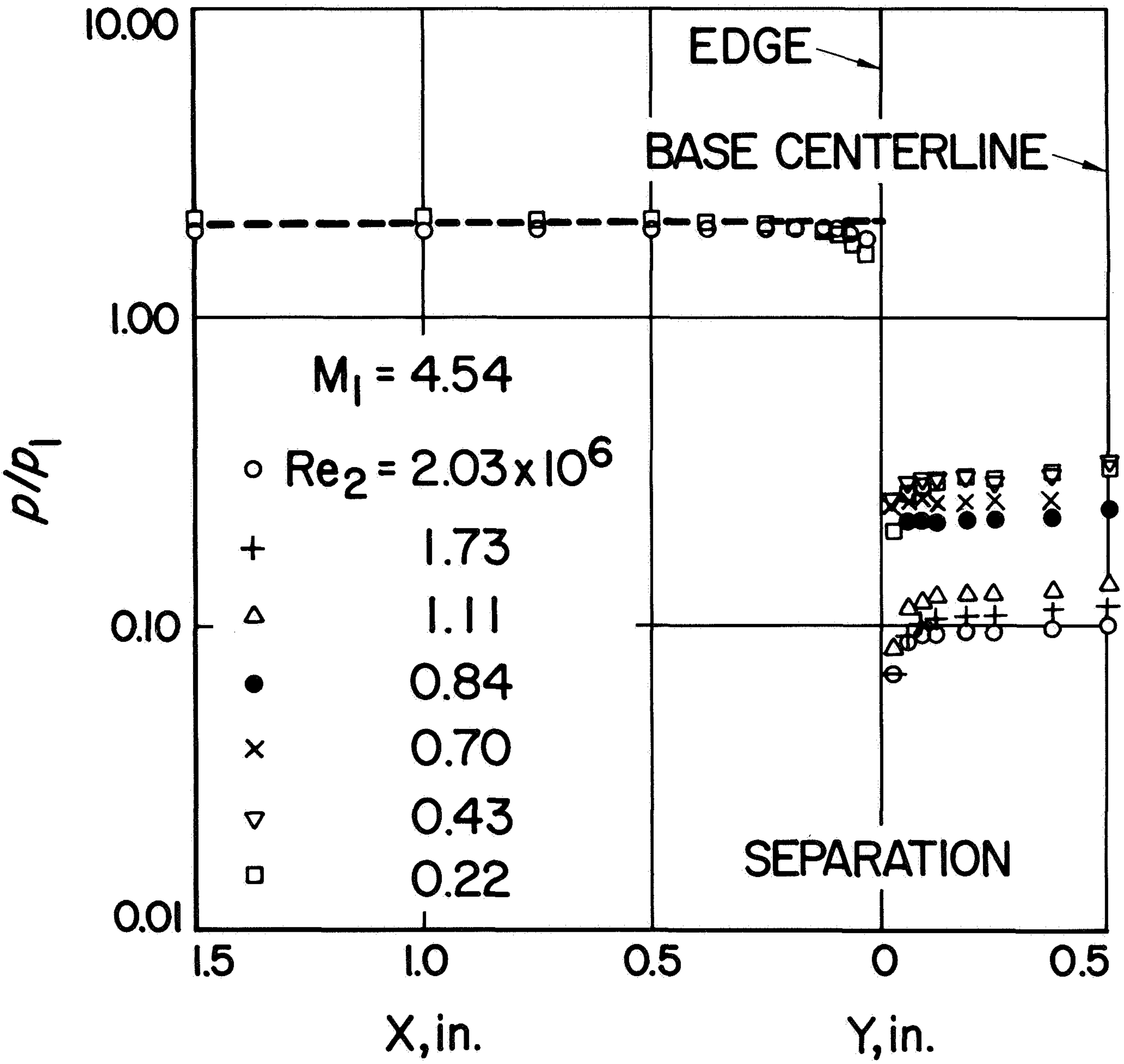
BASE PRESSURE OF WEDGE WITH AND WITHOUT SPLITTER PLATE

CONTINUUM FLUID DYNAMICS



ESTIMATED STRENGTH OF LIP-SHOCK

CONTINUUM FLUID DYNAMICS



PRESSURE DISTRIBUTION AROUND SEPARATION EDGE

Title Rarefied Gas Dynamics

NASA PROGRAM	SCIENCE TASK LEADER	DIRECTED TOWARD WHICH FLIGHT PROGRAM?
129	Dr. H. Ashkenas	

BUDGET (K) | NASA Code: 129-01-10-01-55 | JPL Job. No. 329-10501-1-3270

	E	T	Total	Salary	Proc.	Total Direct	Total Green
FY '65	4.1	2.3	6.4	75	114	189	307
FY '66	3.7	2.5	6.2	68	47	115	221

Total FY '66 Commitments to 1 September 1965 50

OBJECTIVE:

Coordinated theoretical and experimental investigations of shock structure, transition flow and other phenomena related to low-density gas and plasma flow fields.

ABSTRACT:

Solution of the Boltzmann Equation

The success of the simple Bhatnagar-Gross-Krook (BGK) molecular model in describing the shock wave flow is well established. If the model can be generalized, then it may provide a useful tool for the description of rarefied gas flows.

To achieve this aim an iterative solution of the complete Boltzmann equation was attempted. This approach was abandoned because it requires the evaluation, on a digital computer, of a five-fold integral which leads to a great loss of numerical accuracy. Hence they can not constitute a

ABSTRACT (CONT.): Rarefied Gas Dynamics

reliable means for comparison with the solutions of the BGK equation shown in Figs. 1 and 2.

The present phase of research assumes a two-dimensional gas in which the molecules are restricted to move in two directions only. The general behavior of this gas, as well as its transport properties, have been evaluated. The resulting Boltzmann equation is relatively simple and its solution can be obtained accurately on a digital computer. A comparison of this solution with that of the corresponding BGK equation should provide an excellent insight into the making of the BGK model.

Experimental Studies of the Merged Shock-Layer

Measurements are now being made of the density distribution along the stagnation streamline of a 1-inch sphere in a supersonic, low-density, argon stream. A 10 kV electron beam is shot out through the nose of the model and the resulting gas fluorescence is detected with a highly-collimated photomultiplier (see Fig. 1). Flow conditions are readily established wherein the shock thickness equals the inviscid shock stand-off distance. With the use of free jets, it is hoped that the measurements can be extended over the transition range from continuum to near free-molecule flow.

Shock-Strengthening by Area Convergence

A 17-inch diameter shock tube has been coupled with a 10° conical section to a 1-inch shock tube. Measurements indicate that the shock wave has more than tripled its velocity when it reaches the entrance to the 1-inch section (see Fig. 3). Second-order interactions then cause it to decay in strength as it progresses downstream. This motion is being studied as well as the flow uniformity after the shock has passed. Viscous and real gas effects on the shock motion are also being considered.

Spectroscopic Measurements near a Plasma Shock Wave

Electron number density and temperature profiles are being measured in front of a flat disc in a supersonic seeded-gas plasma. The region of interest extends from the disc surface, through the shock, and several body diameters upstream of the disc. Thermally-ionized cesium seeded into argon produces a maximum electron density of 1.5 $(10^{14})/cm^3$ at the supply conditions of the nozzle.

The optical system for the spectroscopic measurements is shown in Fig. 1. The spatial resolution of the system does not allow interpretation of the data on the shock wave itself.

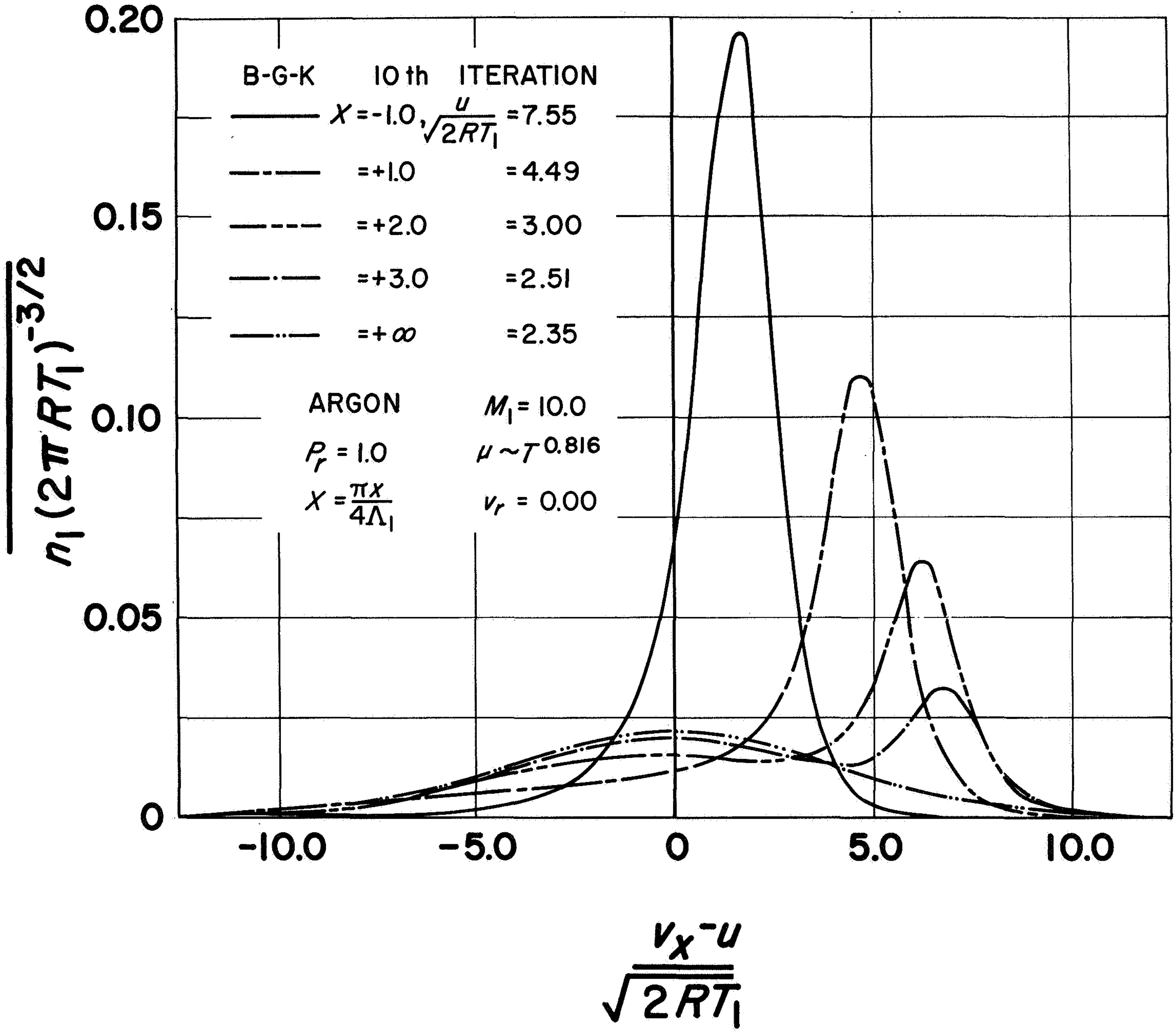
Using theoretical oscillator strengths, absolute line intensity measurements of the diffuse series of cesium are interpreted to give electron density and temperature. Figure 2 shows a typical variation of the number density of excited states of cesium divided by the multiplicity of the state versus the bending energy of the state. The slope of the straight line portion of the graph is proportional to the inverse of the electron temperature. The magnitude of the number density of excited states, together with the Saha equation give the electron density. Results of the spectroscopic measurements indicate that the electron temperature is constant near the shock, but the electron density varies considerably within a body diameter

upstream of the shock wave. Ion current measurements, using the disc itself as a probe, and Langmuir probe measurements lend support to the spectroscopic measurements.

Shock Waves in Binary Mixtures

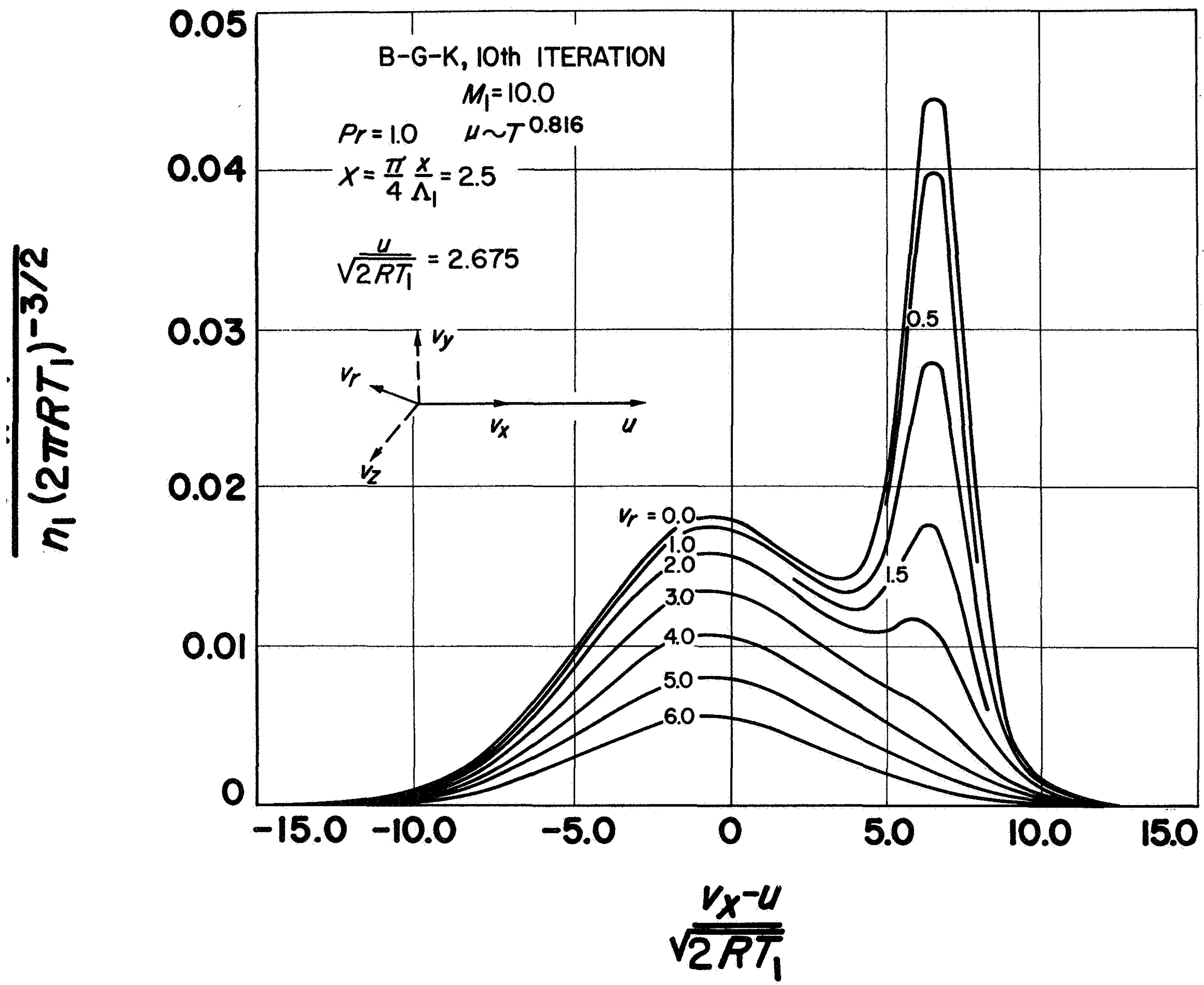
Using He - A mixtures, preliminary measurements have been made of individual component density in a binary mixture shock wave. These measurements have been made for small mole fractions of the heavy component and indicate quite a large separation of the two components in a shock wave.

RARIFIED GAS DYNAMICS



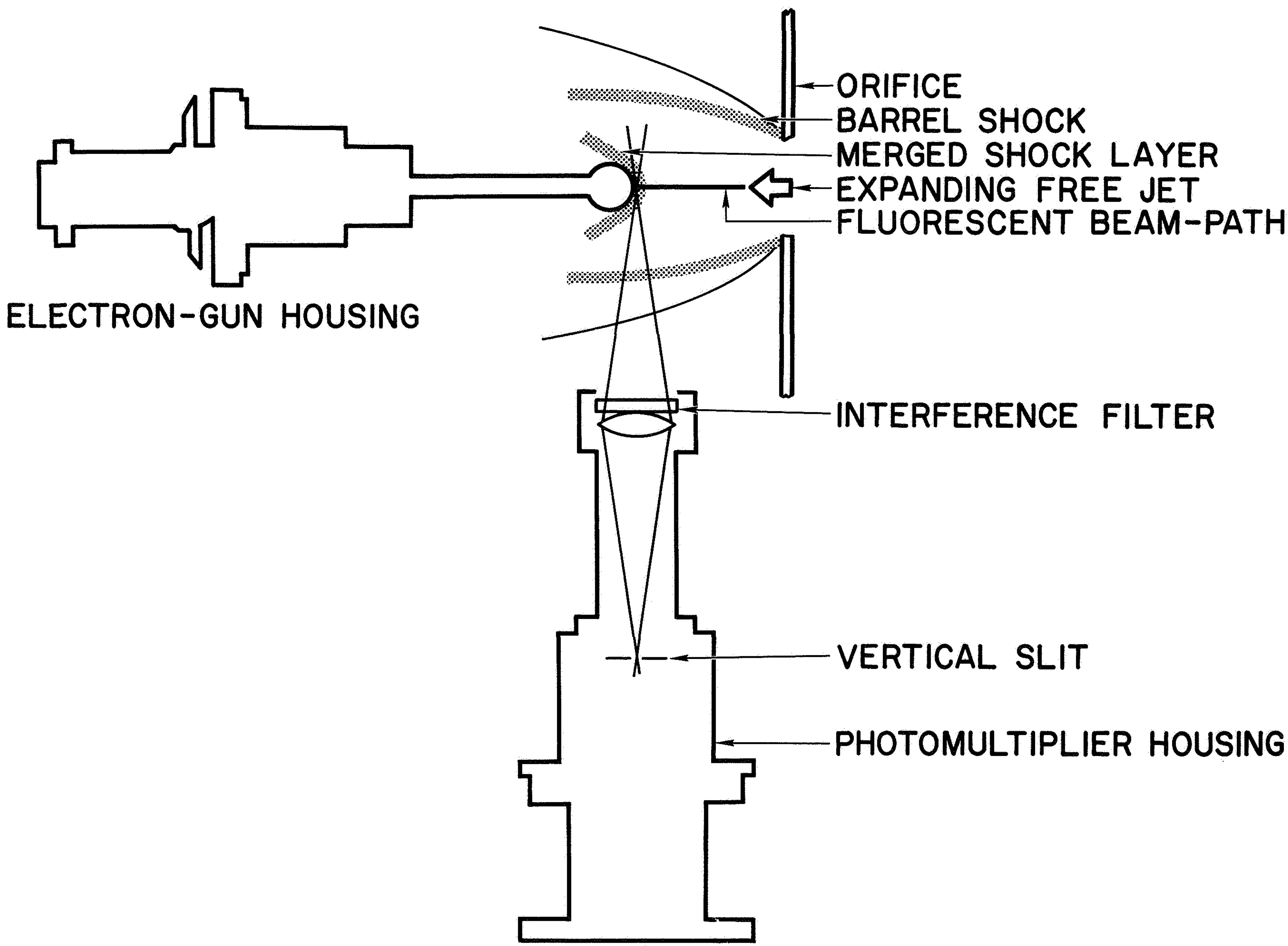
DEVELOPMENT OF THE DISTRIBUTION FUNCTION
ACROSS THE SHOCK WAVE

RAREFIED GAS DYNAMICS



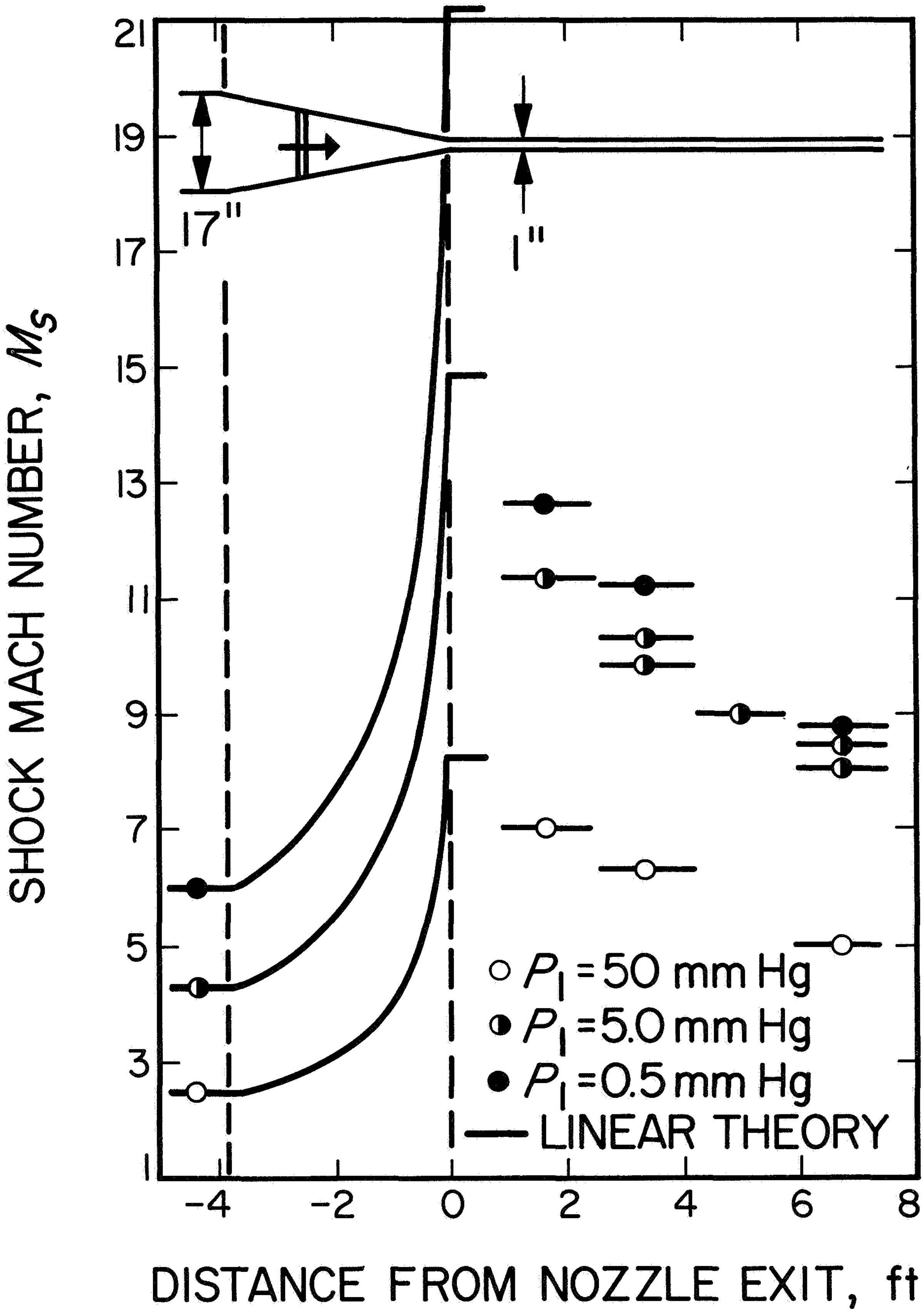
DEPENDENCE OF THE DISTRIBUTION FUNCTION ON v_x AND v_r AT A SPECIFIC X

RAREFIED GAS DYNAMICS

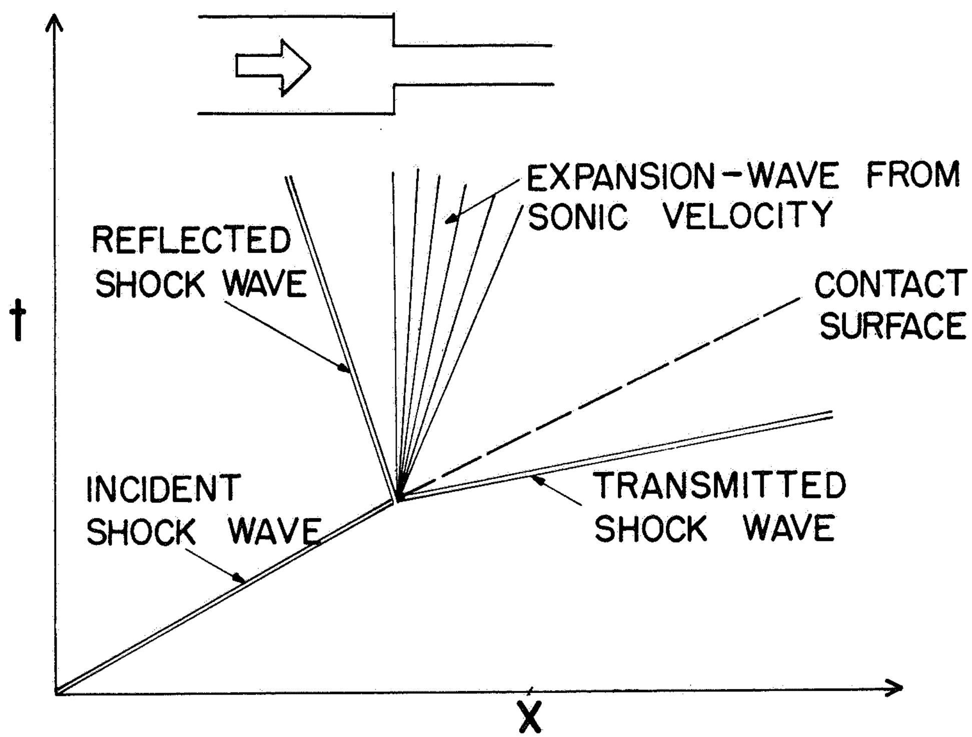


MERGED-LAYER EXPERIMENT

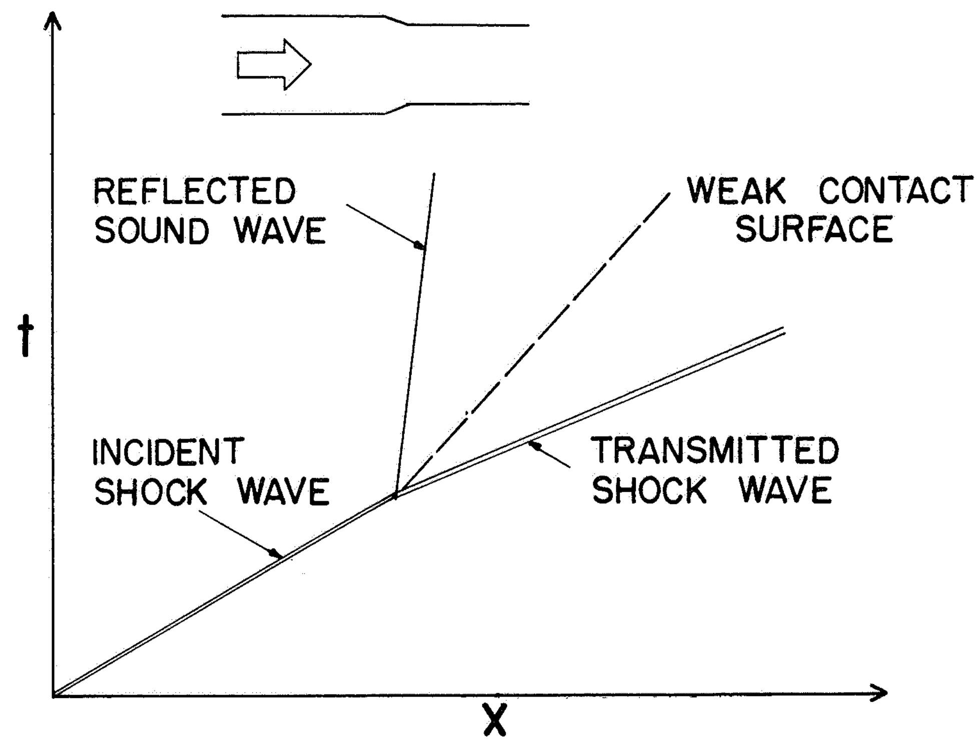
RAREFIED GAS DYNAMICS



SHOCK MOTION DOWNSTREAM OF AREA CONVERGENCE: $\gamma = 5/3$



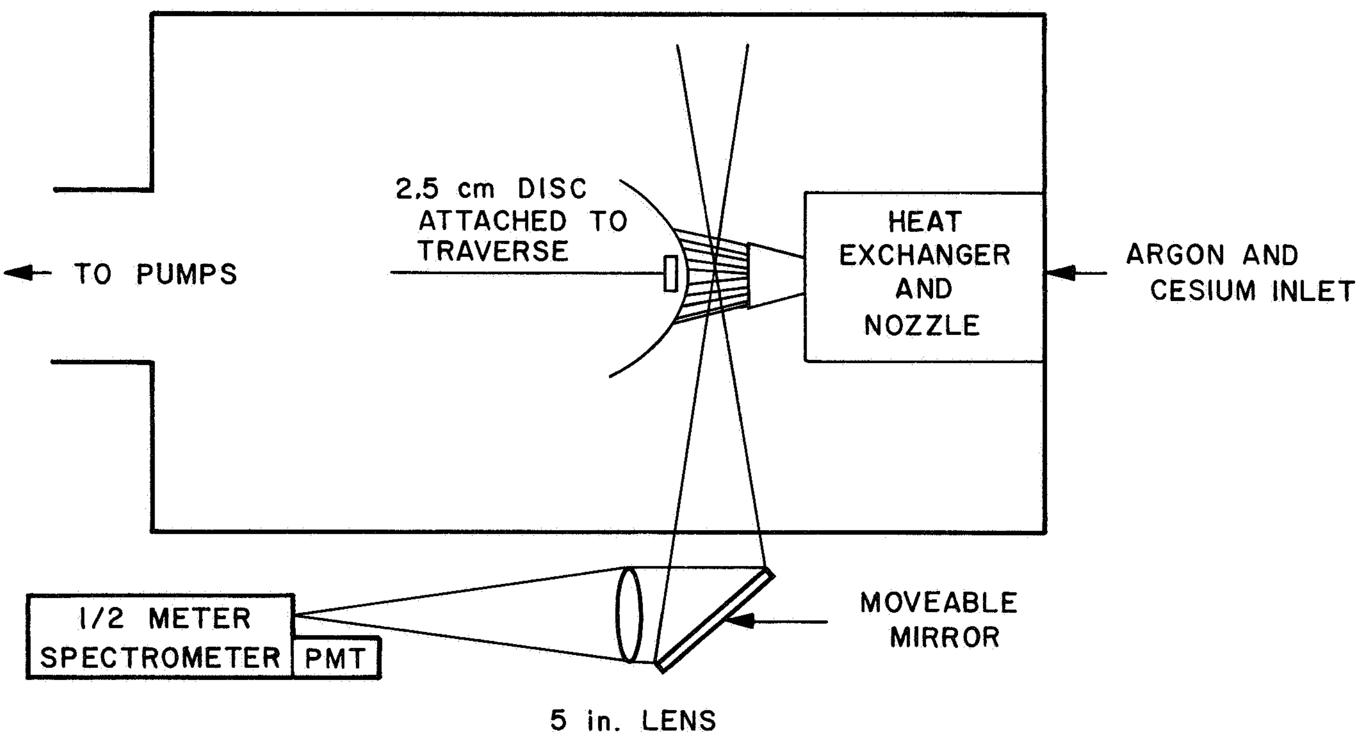
WAVE MODEL FOR FINITE INSTANTANEOUS AREA CHANGE



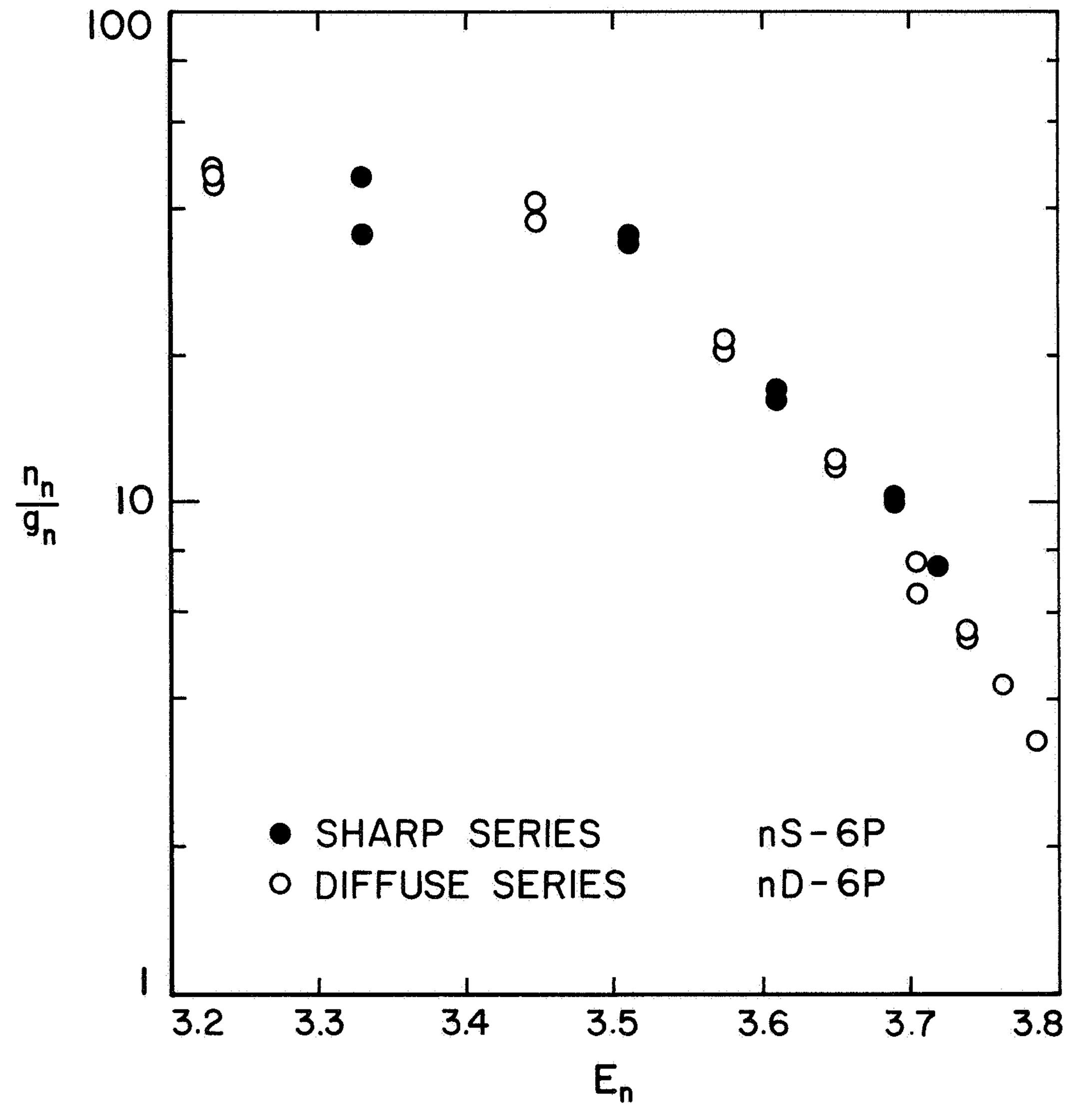
CHISNELL MODEL FOR AN INFINITESIMAL AREA CHANGE

WAVE MODELS FOR THE MOTION OF A SHOCK WAVE THROUGH AN AREA CHANGE

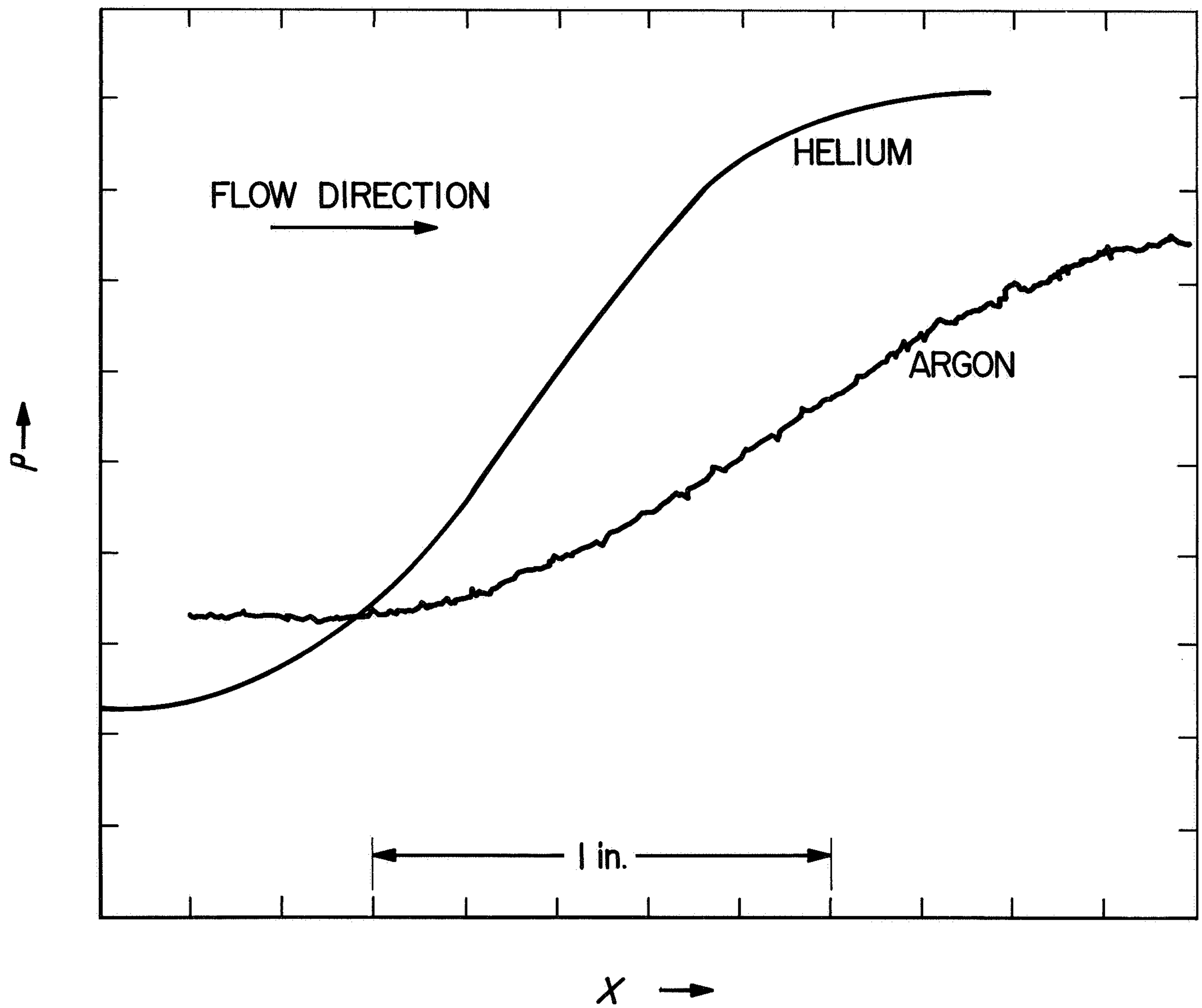
RAREFIED GAS DYNAMICS



SCHEMATIC OF EXPERIMENTAL SETUP IN SEEDED-GAS PLASMA



ELATIVE NUMBER DENSITY OF EXCITED STATES OF CESIUM DIVIDED BY THE JLTIPLICITY OF THE STATE vs BINDING ENERGY OF THE STATE IN ELECTRON VOLTS. THE DATA WERE TAKEN AT AN APPROXIMATE ELECTRON DENSITY OF 6 $(10^{11})/cm^3$



PRELIMINARY EXPERIMENTAL DATA ON DENSITY PROFILES IN A HELIUM-ARGON BINARY MIXTURE SHOCK WAVE (0.038 MOLE FRACTION OF ARGON)

Title Magneto-Fluid Dynamics

NASA PROGRAM	SCIENCE TASK LEADER	DIRECTED TOWARD WHICH FLIGHT PROGRAM?
129	Dr. T. Maxworthy	

BUDGET (K) | NASA Code: 129-01-05-02-55 | JPL Job. No. 329-10801-1-3270

	E	T	Total	Salary	Proc.	Total Direct	Total Green
FY '65	3.2	0.9	4.1	43	53	96	154
FY '66	4.5	0.5	5.0	62	26	88	185

Total FY '66 Commitments to 1 September 1965 26

OBJECTIVE:

To examine the special features of flows with rotation and of flows in magnetic fields in order to understand the role of magnetic and Coriolis forces in natural and technological processes.

ABSTRACT:

Liquid Sodium Tunnel

I. Equipment

The following major items have been constructed since the last review:

(i) An improved probe traversing mechanism: With our greater experience in liquid metal technology, we are now able to design a more complicated and versatile mechanism than that presently in use.

(ii) A drag balance, using a three-wire suspension system, to measure the drag forces experienced by spheres and discs in "aligned

ABSTRACT (CONT.): Magneto-Fluid Dynamics

field" flow.

(iii) A sphere model that is designed to measure surface static pressure as a function of angular position around the sphere. By observing the change in the character of the pressure distribution as the magnetic field is applied, one can infer changes in the flow field, e.g., development of slug flow, changes in separation phenomena.

(iv) A magnetic probe at fixed axial location ahead of the pressure measuring sphere (iii). The sphere model is to be moved radially behind the probe to observe the magnetic character of the predicted "forward disturbance" associated with the flow around the sphere. We can observe the effect of the probe on the pressure distribution around the sphere and hence infer its effect on the flow field itself.

II. Experiments

(i) Sphere and Disc Drag

When the interaction parameter, N (ratio of magnetic to inertia forces) is large, a linear dependence of drag on N is observed for both spheres and discs. The constants of proportionality are slightly different in the two cases, suggesting a slightly different flow field in this limit for the two body shapes, Figs. 1 and 2. At low N and low Re an anomalous behavior is observed, possibly associated with separation of the boundary layer on the tunnel walls, Figs. 3 and 4.

ABSTRACT (CONT.): Magneto-Fluid Dynamics

This possibility is being checked.

(ii) Sphere and Slender Body Wakes

An effort is being made to directly observe the magneto-fluid dynamic flow field of a body with a normally separated wake (sphere) and one with a normally unseparated wake (slender body). At large N, both wake types tend to a stagnant slug immediately behind the body with a region of increased velocity at larger radial distances, Figs. 5 and 6.

(iii) Theory

A linearized, small perturbation theory has been constructed to explain the flow field observed as the fluid in the empty tunnel exits through the fringing solenoidal magnetic field. Exponential decay of exit disturbances is predicted theoretically and observed experimentally.

Rotating Flows

(i) Sphere drag at low Re has been reported in the literature, showing a general agreement with the theoretical work based on the technique of matched or inner and outer expansions.

(ii) Sphere drag measurements at high Re show a linear dependence of drag coefficient on interaction parameter, S (ratio of Coriolis to inertia forces), c.f., corresponding magneto-fluid dynamic measurements, Fig. 7.

ABSTRACT (CONT.): Magneto-Fluid Dynamics

(iii) Flow field measurements at high Re, using both dye and hydrogen bubble techniques, show the existence of slug flow fore and aft of a sphere with decaying wakes extending beyond the slugs, Fig. 8.

Geophysical Fluid Dynamics

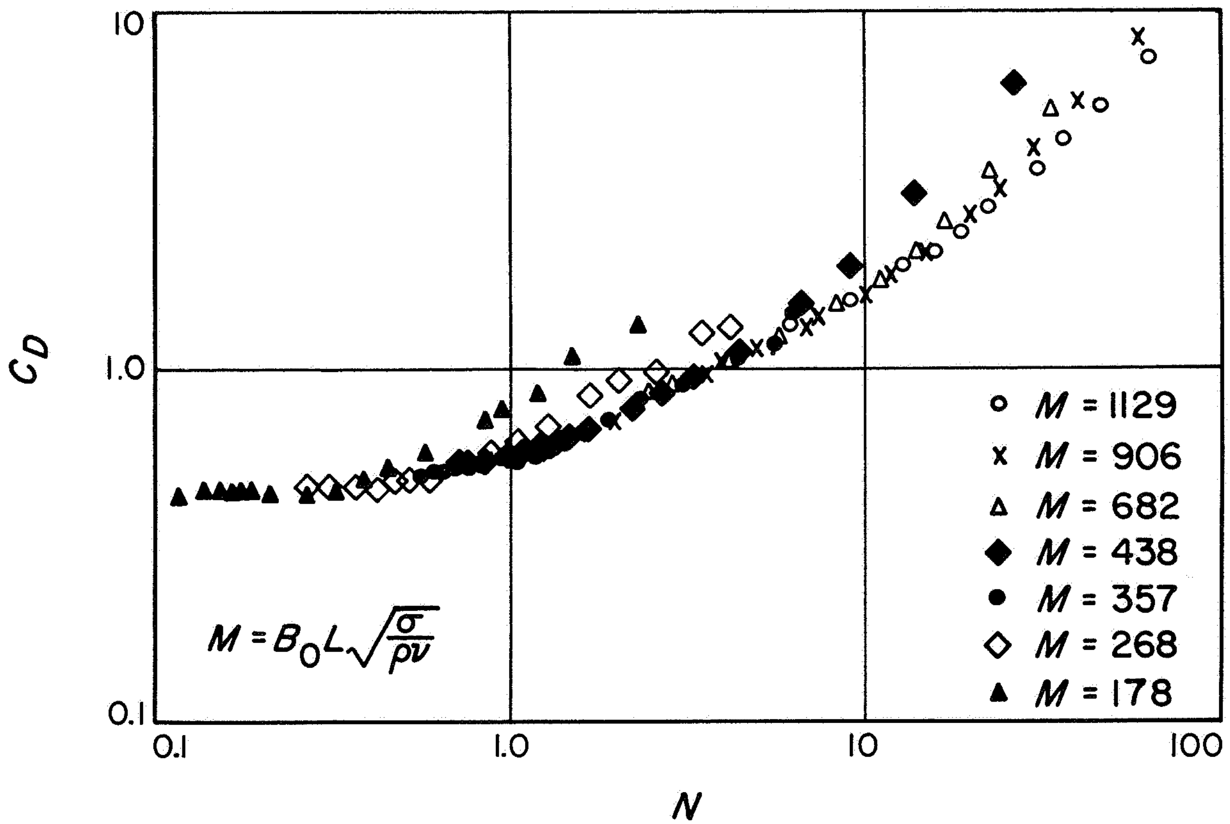
(i) New Equipment

A general-purpose rotating tank apparatus has been built. It can be used for a variety of rotating flow experiments. Initially a rotating, boundary layer study is to be performed.

(ii) Flow due to a laboratory tornado. The interaction of a rapidly swirling sink flow and a stationary surface has been observed. The boundary layer flow is different from that which one would expect by considering flow produced by the centrifugal pressure gradient of the swirling outer flow only. The axial flow created by the sink flow itself is also imposed upon the boundary layer and modifies its behavior, Fig. 9.

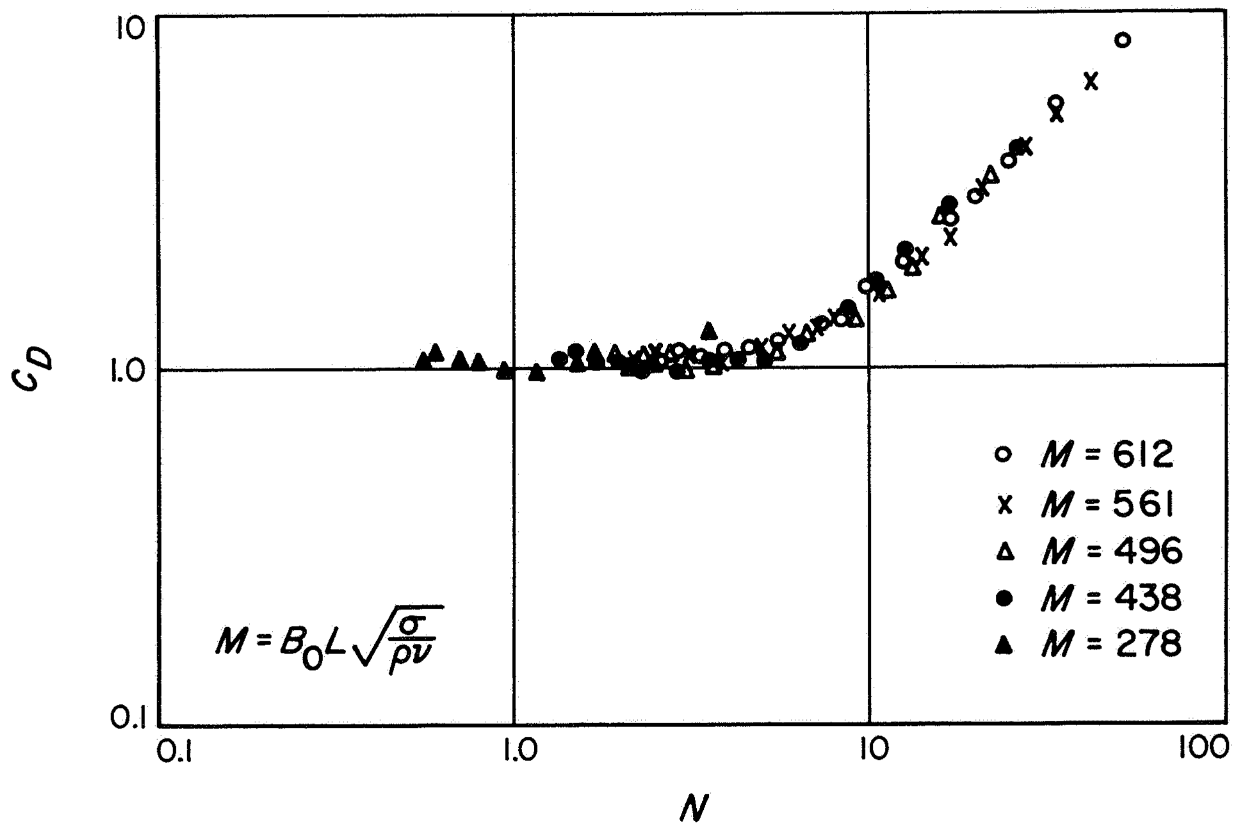
(iii) Boundary layer on a stationary disc with solid-body outer flow. These boundary layers have the oscillatory character associated with motion in an infinite domain, even though they are produced in a container of moderate dimensions, Fig. 10.

MAGNETO FLUID DYNAMICS



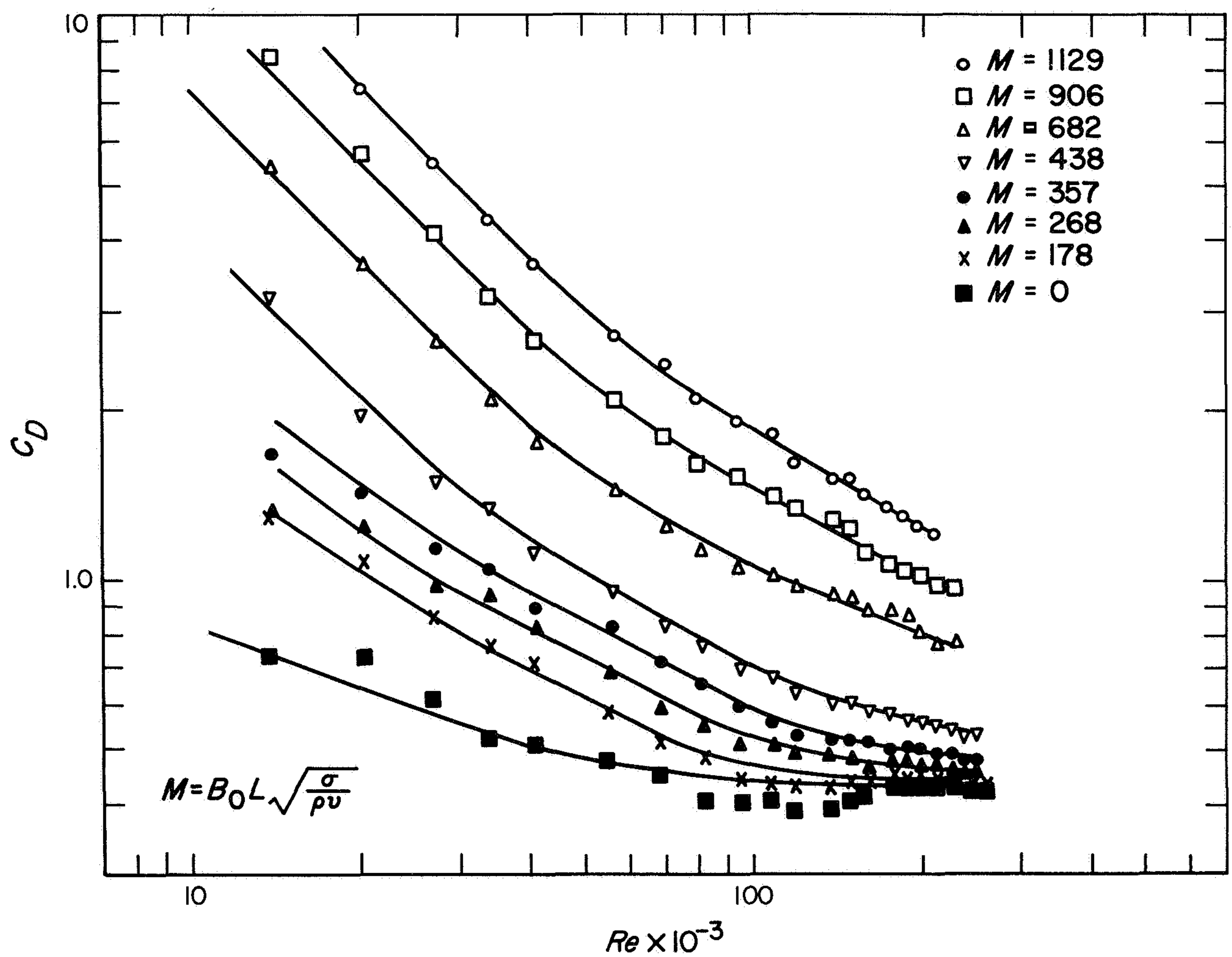
DRAG COEFFICIENT C_D vs INTERACTION PARAMETER $N = B_0^2 \sigma L / \rho u_0$ FOR 0.500-in. SPHERE AT VARIOUS HARTMANN NUMBERS M

MAGNETO FLUID DYNAMICS



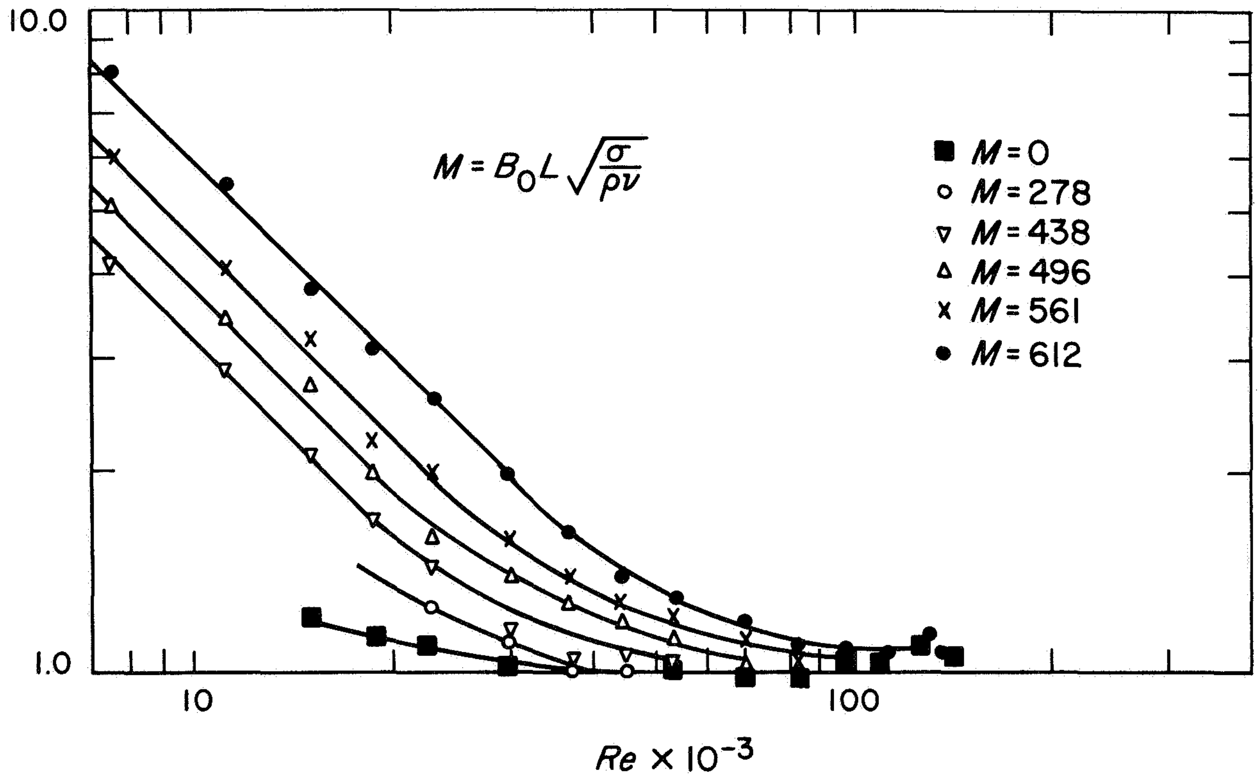
DRAG COEFFICIENT C_D vs INTERACTION PARAMETER $N = B_0^2 \sigma L / \rho u_0$
FOR 0.274-in. DISK AT VARIOUS HARTMANN NUMBERS M

MAGNETO FLUID DYNAMICS



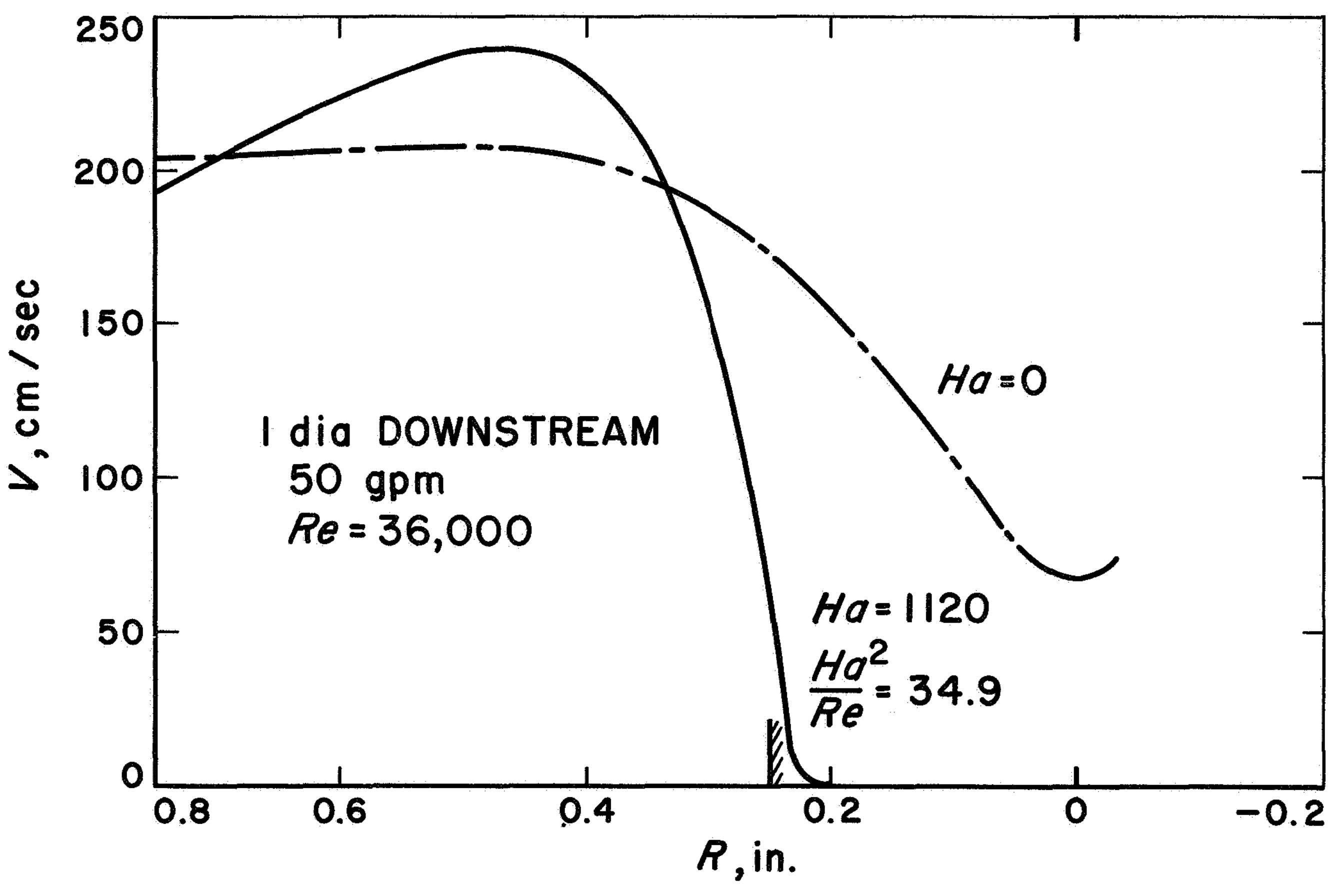
DRAG COEFFICIENT C_D vs REYNOLDS NUMBER Re
FOR 0.500-in. SPHERE AT VARIOUS HARTMANN NUMBERS M

MAGNETO FLUID DYNAMICS



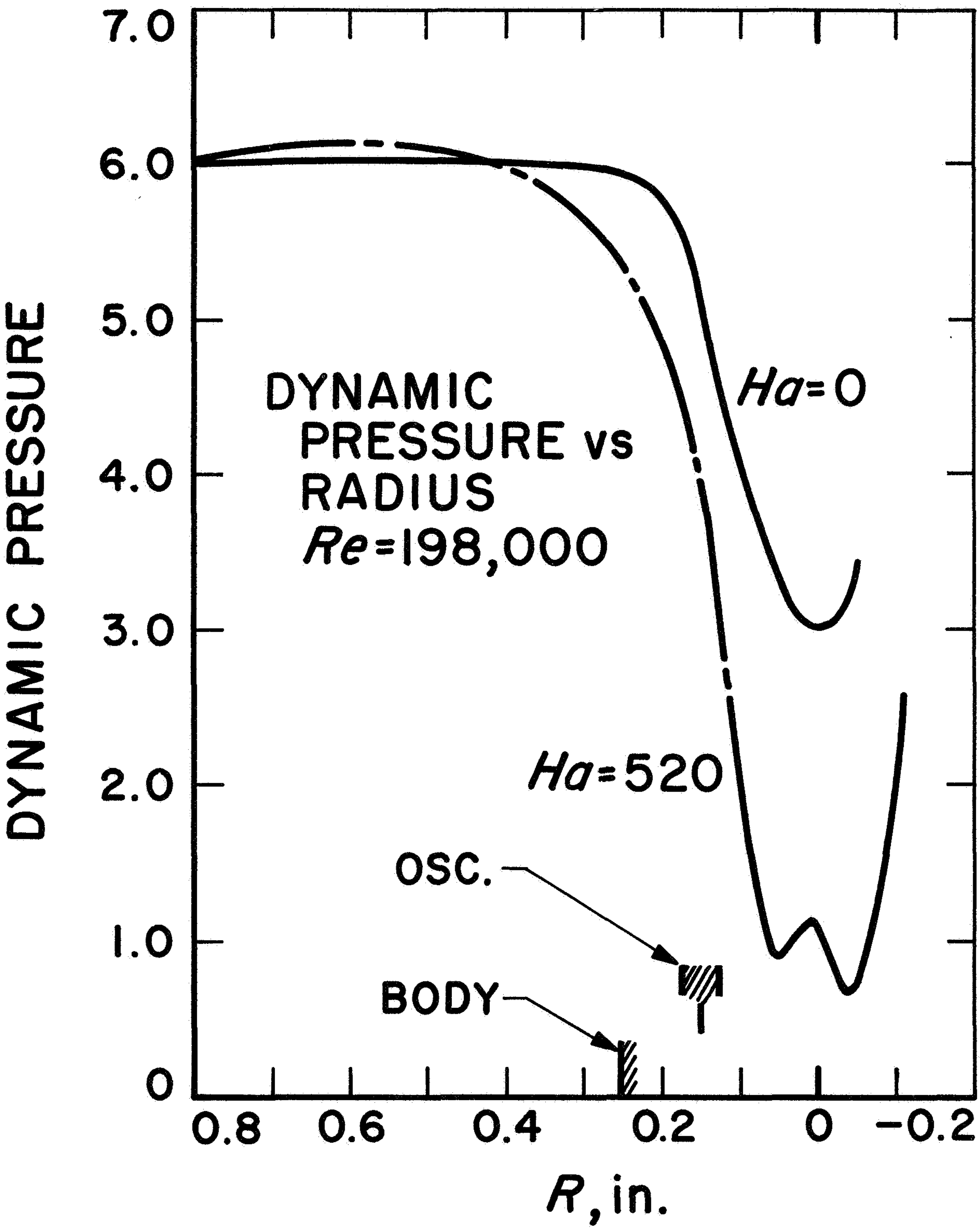
DRAG COEFFICIENT C_D vs REYNOLDS NUMBER Re
FOR 0.274-in. DISK AT VARIOUS HARTMANN NUMBERS M

MAGNETO FLUID DYNAMICS



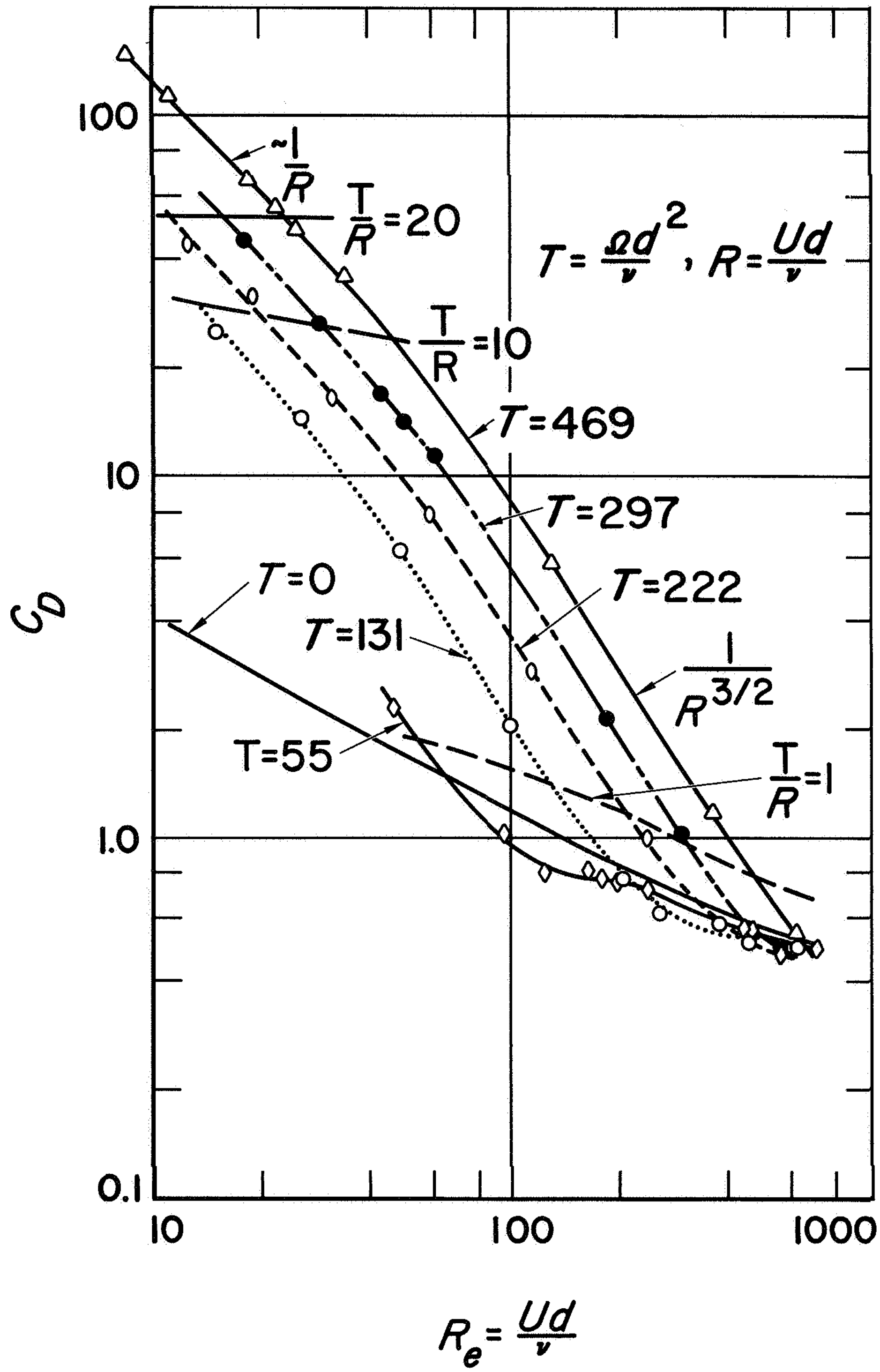
SPHERE WAKES, VELOCITY PROFILES

MAGNETO FLUID DYNAMICS



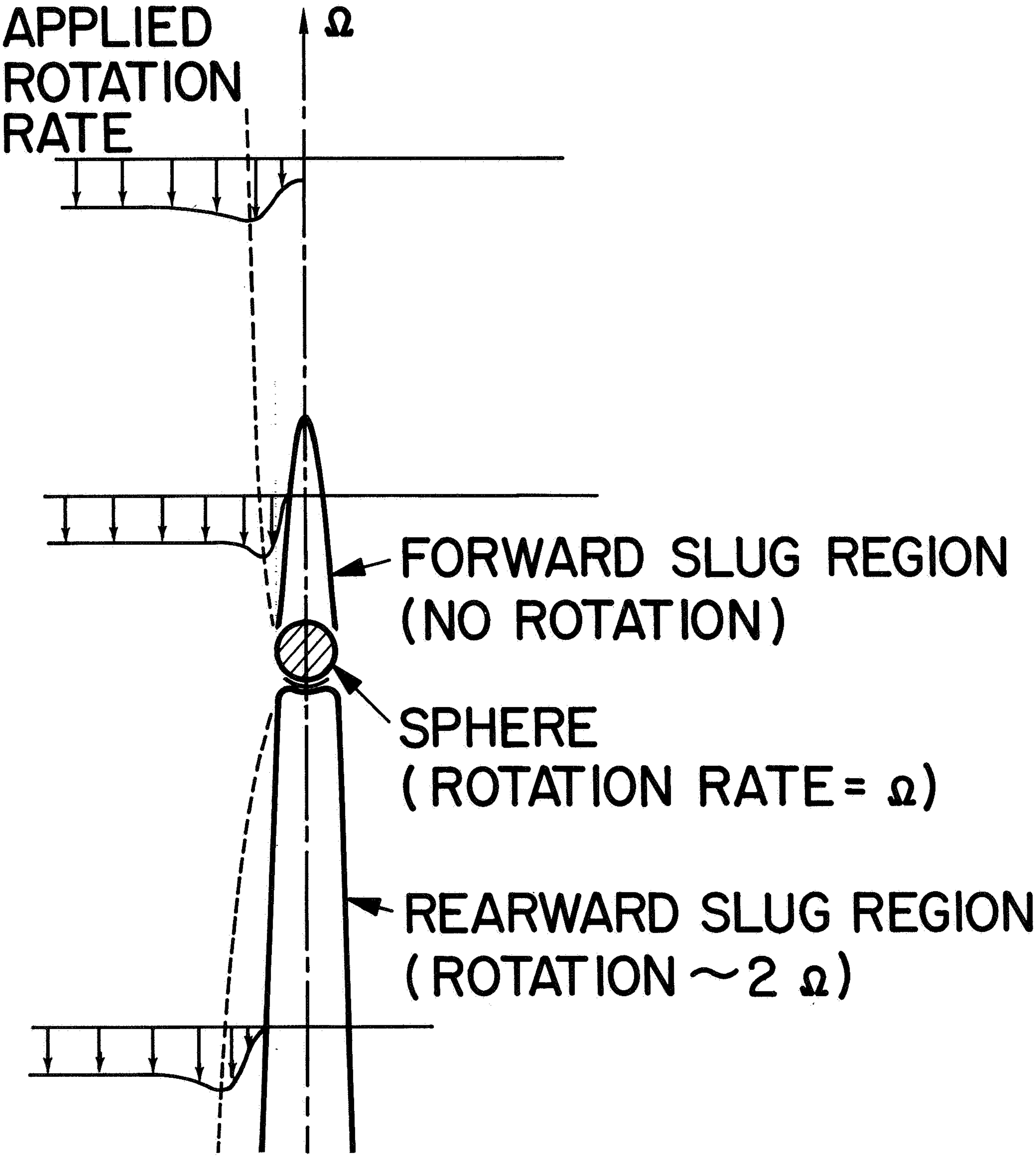
SLENDER BODY WAKES

MAGNETO FLUID DYNAMICS



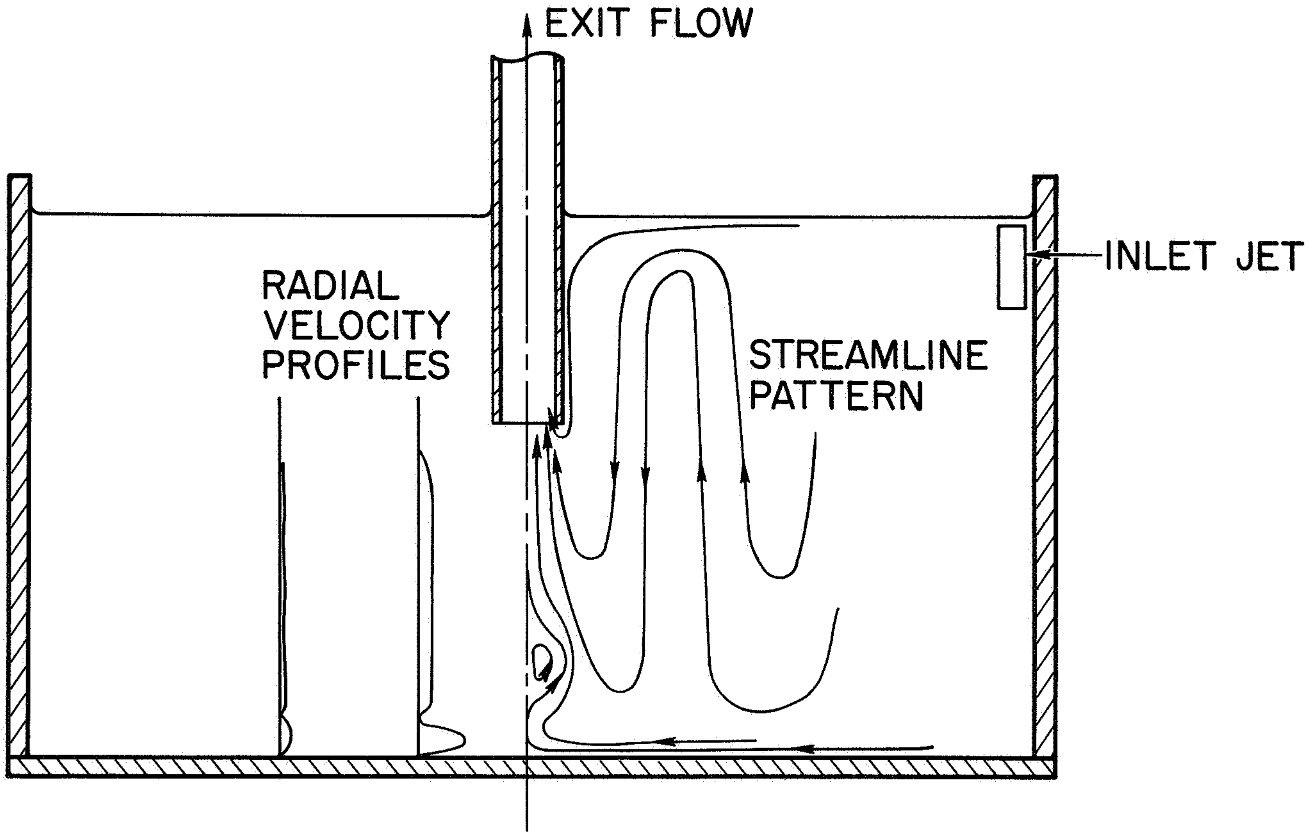
SPHERE DRAG IN A ROTATING FLUID

MAGNETO FLUID DYNAMICS



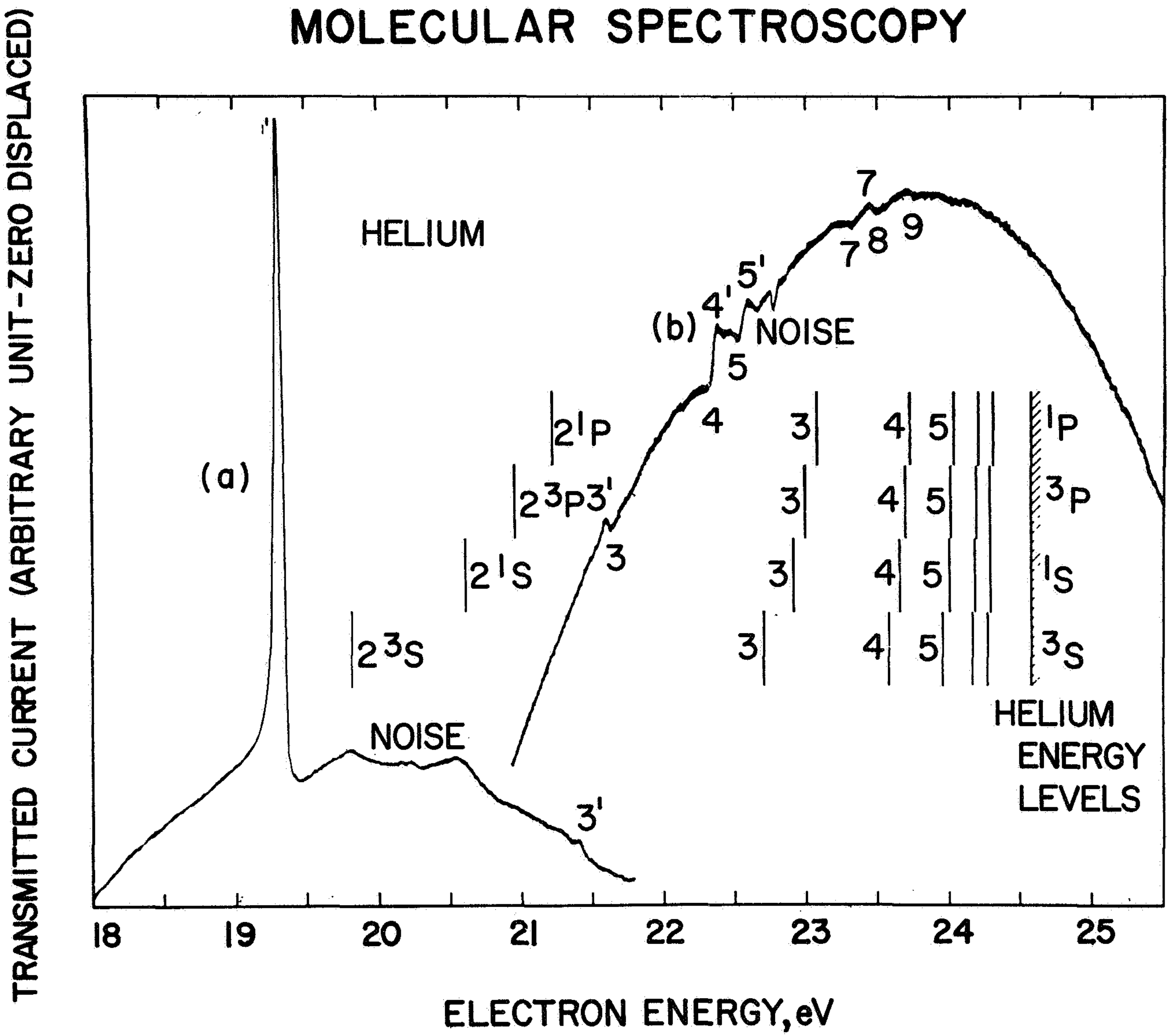
FLOW FIELD OF A SPHERE
IN A UNIFORM, ROTATING FLUID

MAGNETO FLUID DYNAMICS



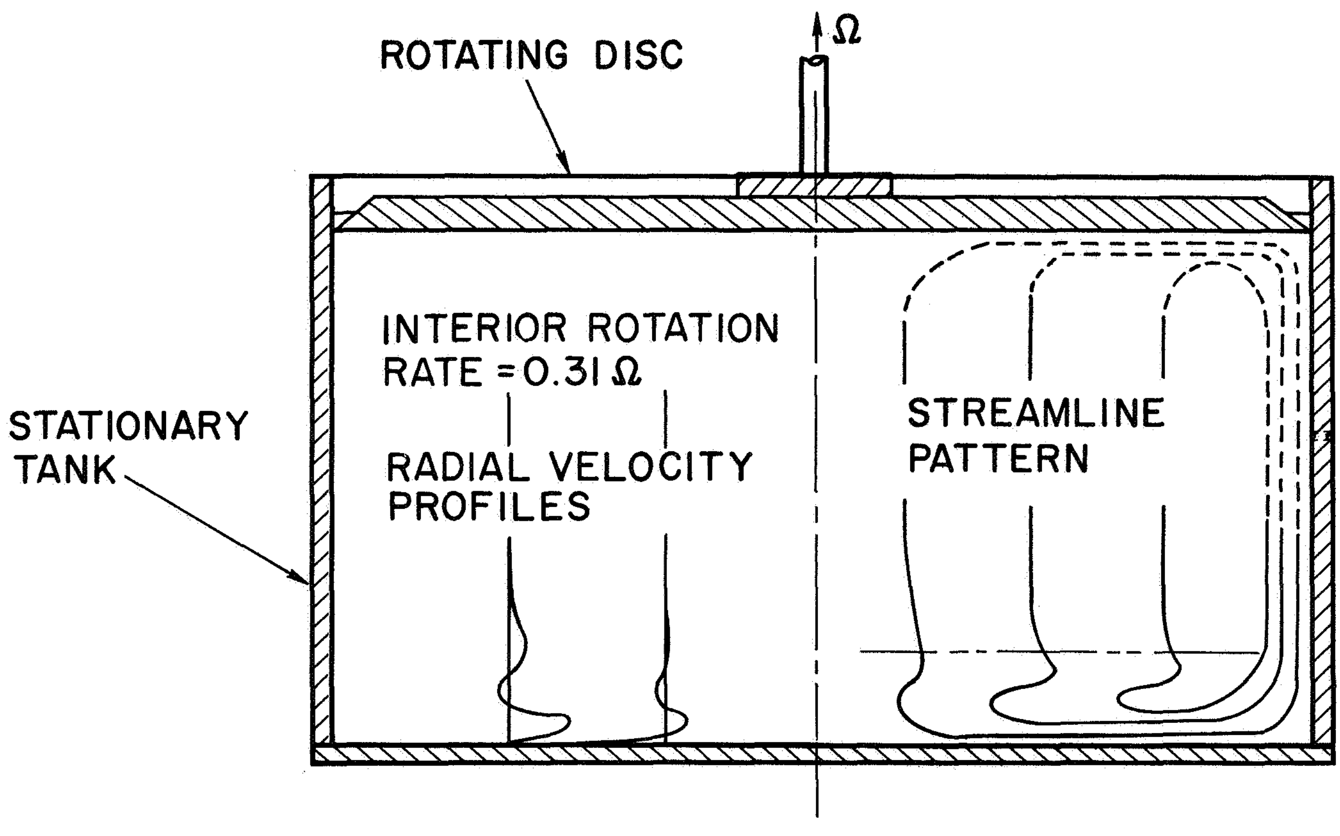
FLOW PATTERN OF A VISCOUS VORTEX
INTERACTING WITH A STATIONARY PLANE

MOLECULAR SPECTROSCOPY



ELASTIC RESONANCE IN HELIUM

MAGNETO FLUID DYNAMICS



FLOW DUE TO A DISC ROTATING IN A
STATIONARY CYLINDRICAL CONTAINER

Title Shock-Heated Plasmas and Jet Structure

NASA PROGRAM	SCIENCE TASK LEADER	DIRECTED TOWARD WHICH FLIGHT PROGRAM?
129	Dr. H. Ashkenas	

BUDGET (K) NASA Code: 129-01-05-03-55 JPL Job. No. 329-11301-2-3270

	E	T	Total	Salary	Proc.	Total Direct	Total Green
FY '65	1.3	0.4	1.7	21	31	52	83
FY '66	1.7	0.5	2.2	26	25	51	91

Total FY '66 Commitments to 1 September 1965 6

OBJECTIVE:

To develop diagnostic techniques to be used in plasmadynamic and aerodynamic facilities, as well as to carry out basic experiments relating to the astrophysical and planetary entry problems.

ABSTRACT:

Resonant Scattering

It is proposed to use resonant scattering techniques to obtain local Doppler information on non-steady gas flows and hence to examine the distribution function. As a first step, a study has been undertaken of resonant scattering/absorption from a static gas. Resonant absorption has been detected off the 10,829 Å line in He from the 2^3S metestable state.

Use of High Energy Electron Beams in Neutral and Partially Ionized Gas Flows

Some measurements have been made in a static gas to investigate the multiple scattering of fast electrons and the transition regime from single

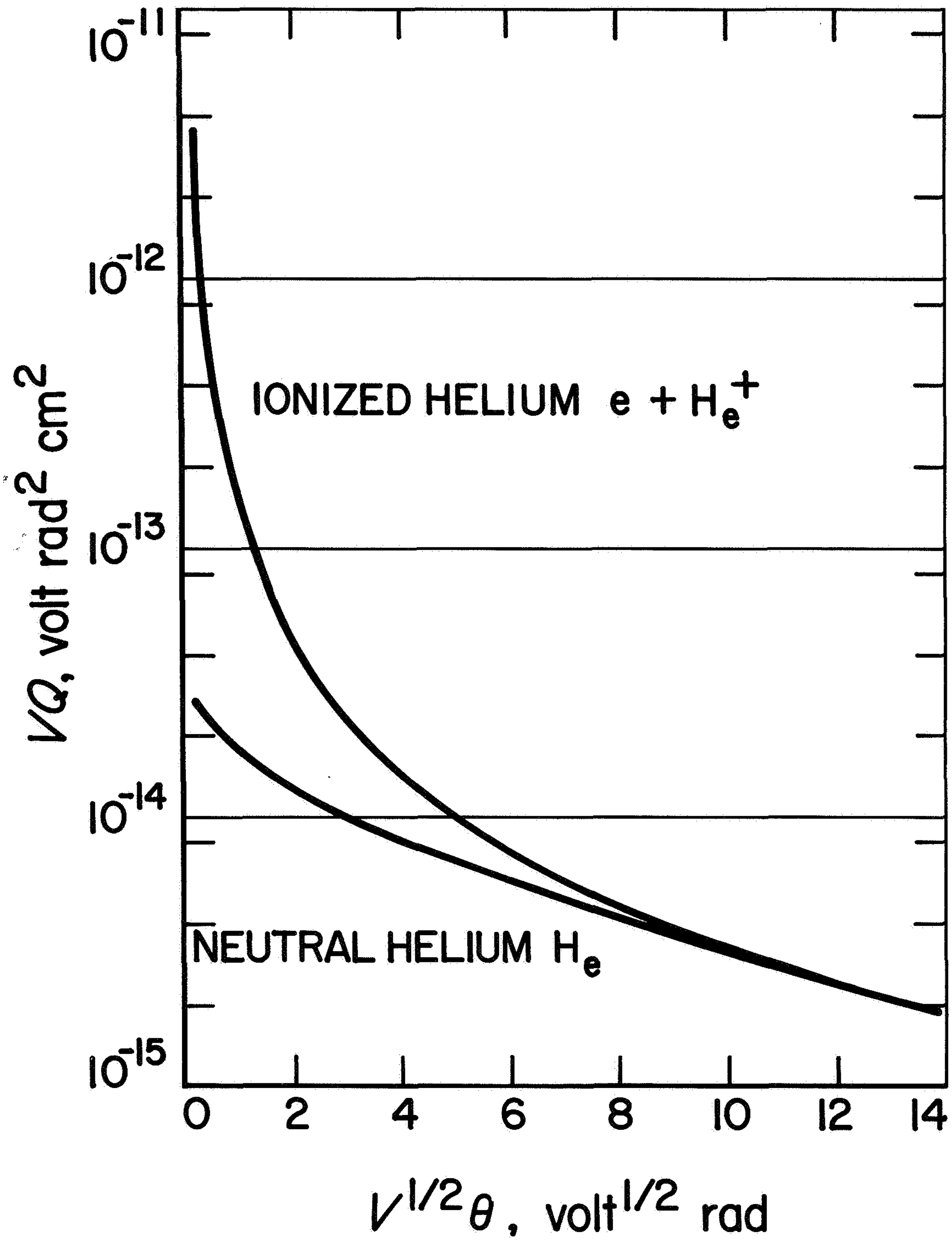
ABSTRACT (CONT.): Shock-Heated Plasmas and Jet Structure

to multiple scattering. Difficulty has been experienced in obtaining sufficient collimation in the electron beam. It is hoped to apply knowledge gained from these multiple scattering measurements to the proposed scattering experiments in a partially ionized gas. These experiments await the availability of the free-piston shock tube.

Viscous Free Jet Structure

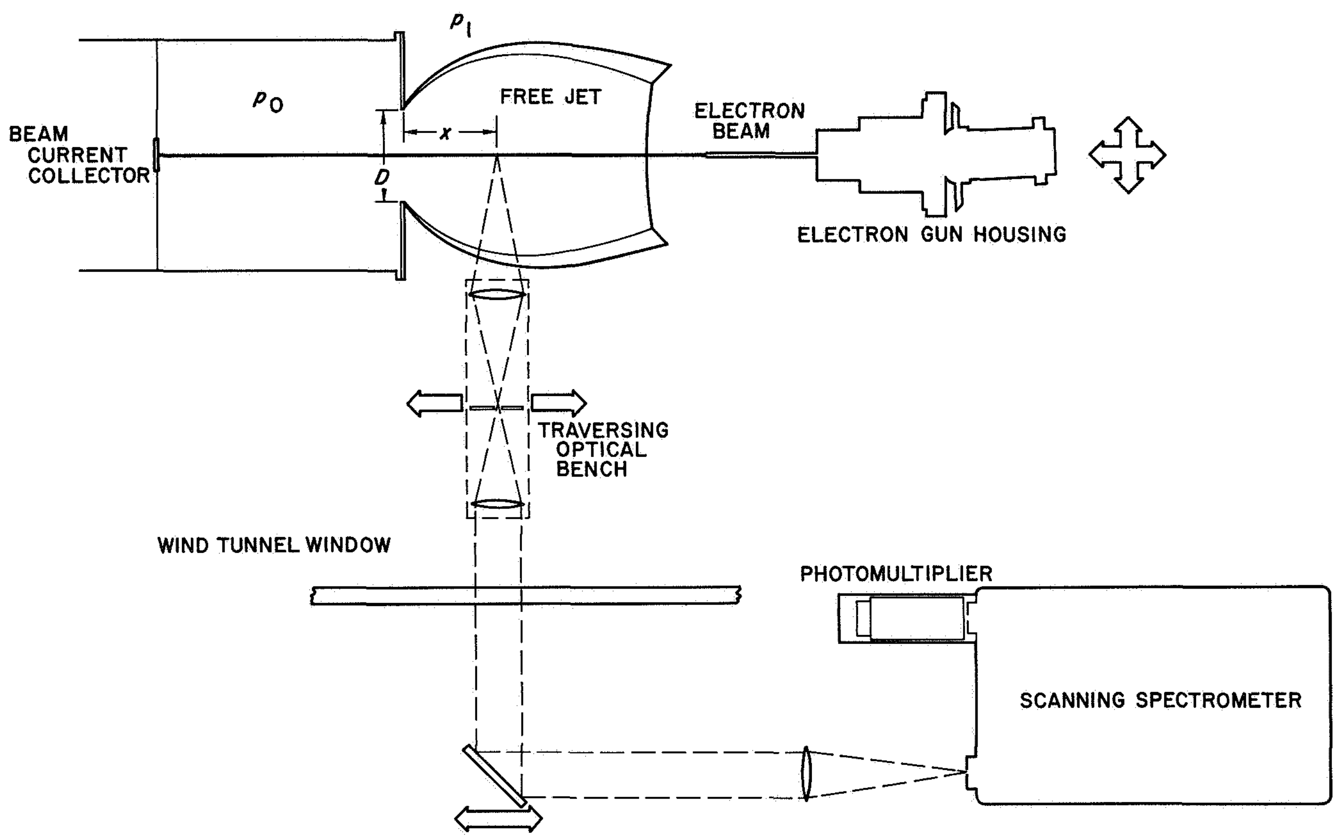
The structure of the low-density free jet is being studied through the use of electron-beam diagnostic techniques. Jet structure measurements are being made in the Reynolds number range where large viscous dissipative effects have been postulated. Rotational temperature measurements in a nitrogen jet have been made by examining the rotational fine-structure of an electron-beam excited emission, using the setup sketched schematically in Fig. 1. The results of some of the initial measurements are shown in Fig. 2. Further diagnosis of the jet parameters will involve the measurement of local density, by means of electron-beam fluorescence intensity measurements. These data will be combined with the rotational temperature data to obtain the complete structure of the jet.

SHOCK HEATED PLASMAS AND JET STRUCTURE

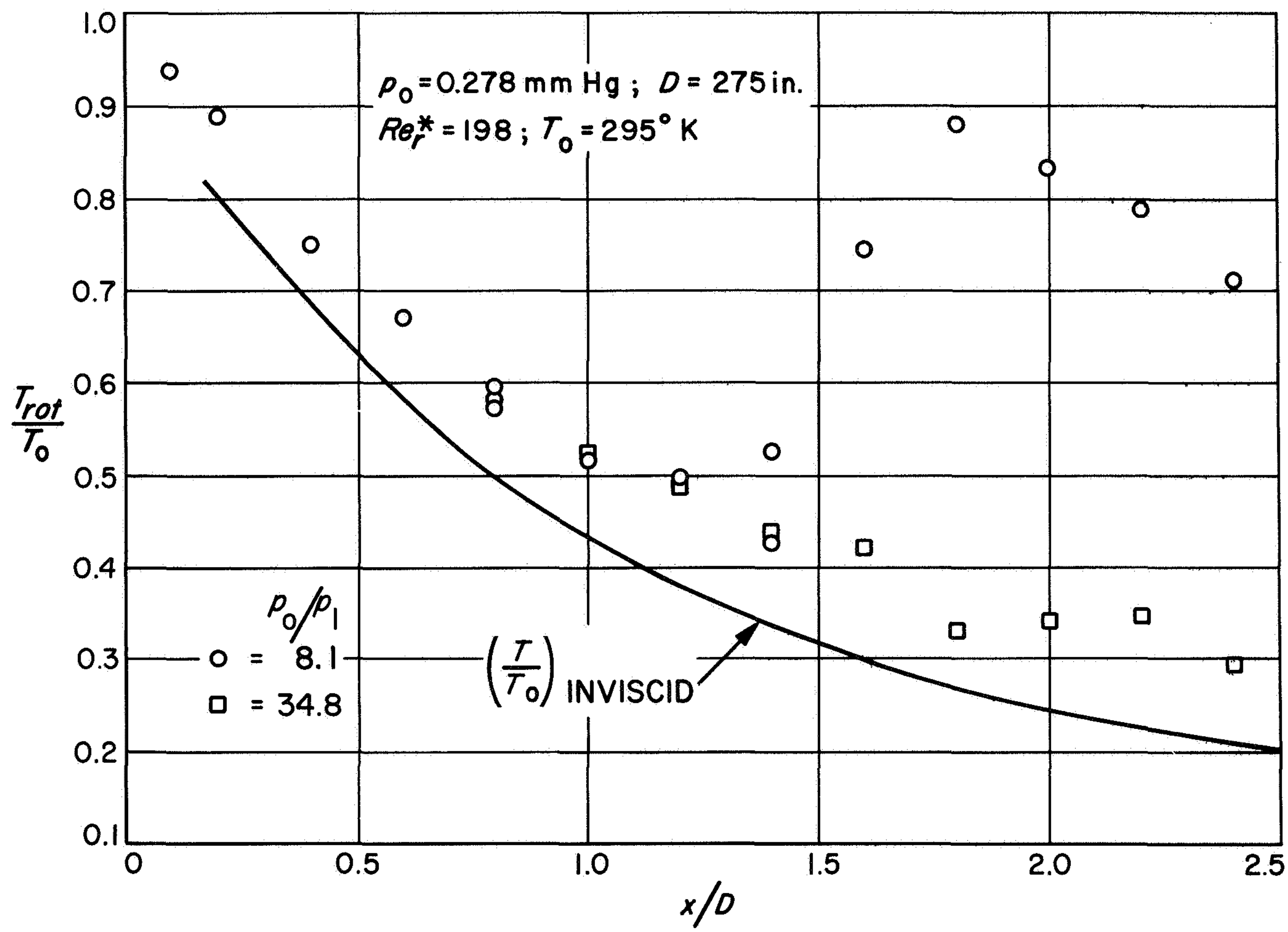


THEORETICAL CROSS-SECTION DATA FOR HIGH-ENERGY ELECTRON COLLISIONS WITH NEUTRAL AND IONIZED HELIUM

SHOCK HEATED PLASMAS AND JET STRUCTURES

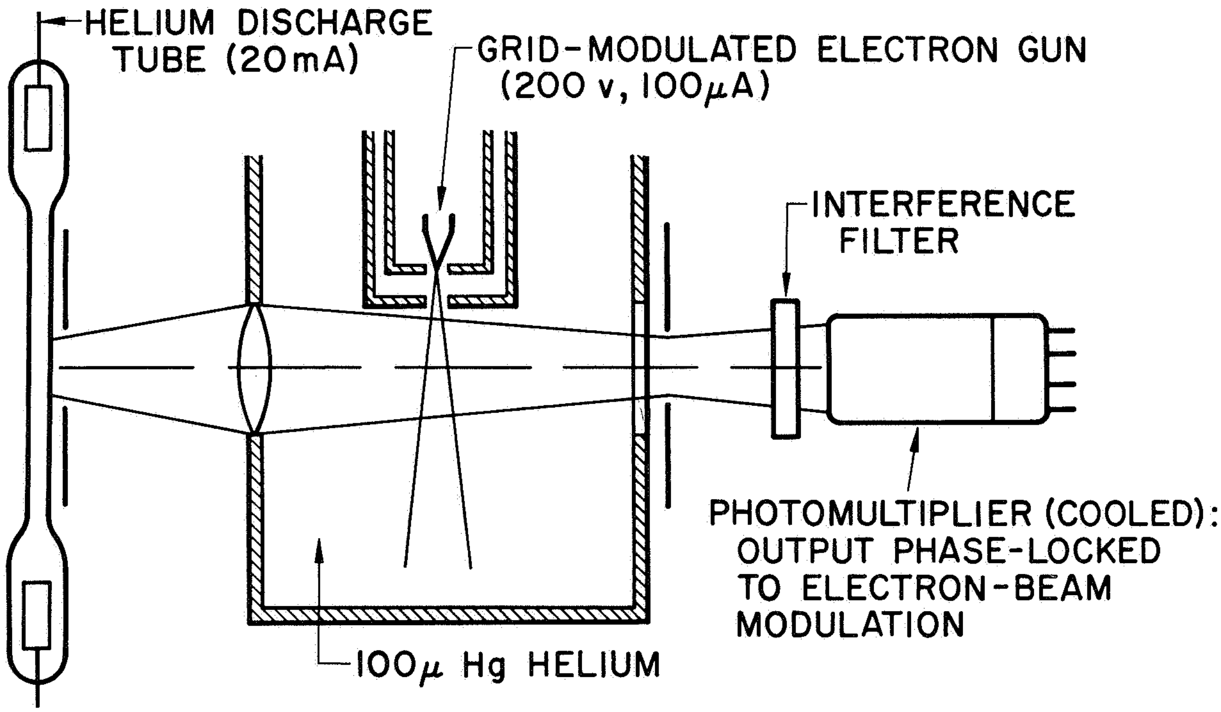


SETUP FOR THE MEASUREMENT OF ROTATIONAL TEMPERATURE DISTRIBUTION ALONG THE AXIS OF THE FREE JET



ROTATIONAL TEMPERATURE DISTRIBUTION IN NITROGEN FREE JET

SHOCK HEATED PLASMAS AND JET STRUCTURE



SCHEMATIC OF EXPERIMENT: SCATTERING OF 10,829 Å HELIUM RADIATION OFF 2^3S METASTABLE STATE IN EXCITED HELIUM

ELECTRO PHYSICS - DIVISION 32

TITLE NASA Code JPL Code	FISCAL YEAR	PROFESSIONAL MAN-YEARS	DOLLARS (in 000's)
Photochemistry			
129-02-03-02 329-21001-1-3260	1964 1965 1966	2.2 2.0 1.8	100 70 100
Plasma Physics Research			
129-02-03-03 329-20701-1-3280	1964 1965 1966	5.0 2.8 2.7	251 178 142
Quantum Chemistry			
129-02-03-04 329-20801-1-3260	1964 1965 1966	1.5 0.9 0.9	120 70 81
Radiation Chemistry			
129-02-03-06 329-21301-1-3260	1964 1965 1966	1.0 0.9 0.9	55 45 70
Nuclear Physics Research			
129-02-03-08 329=21701-1-3280	1964 1965 1966	2.5 1.8 1.8	278 172 241
Low Temperature Physics			
129-02-05-04 329-20401-1-3280	1964 1965 1966	2.0 1.8 1.1	131 120 120
Theoretical Physics			
129-02-07-02 329-20901-1-3280	1964 1965 1966	8.0 7.2 5.4	338 262 200

Title QUANTUM CHEMISTRY

NASA PROGRAM	SCIENCE TASK LEADER	DIRECTED TOWARD WHICH FLIGHT PROGRAM?
129	Murray Geller	

BUDGET (K) | NASA Code: 129-02-03-04 | JPL Job. No. 329-20801-1-3260

	E	T	Total	Salary	Proc.	Total Direct	Total Green
FY '65	1	0	1	15	34	49	70
FY '66	1	0	1	15	38	58	81

Total FY '66 Commitments to 1 September 1965 22

OBJECTIVE: Extend Be atom calculations (by Sinanoglu many-electron theory) to first row isoelectronic series, viz., B^+, C^{++},... to learn how correlation energy varies with atomic number in the different shells and the efficacy of the Simanoglu approach.

Develop working Hartree-Fock program for triatomic molecules.

Develop efficient techniques for exchange integrals and for multicenter integrals.

Verify theory for analyzing negative ion resonant elastic scattering states where variation principle no longer applicable.

Analysis of correlation effects by extension of Pluvinage's approach, analysis of small diatomics by elliptical coordinate method, techniques for developing infinite configuration interaction approach to atoms and molecules and lastly, analysis of upper and lower bounds and convergence properties of trial wave functions so as to assess their goodness.

ABSTRACT:

Ab-initio calculation of Be atom by the Sinanoglu many-electron theory completed and published, J. Chem. Phys. 43, 1727 (1965) Sept. 1, and 98% of the correlation energy has been accounted for. The calculation has been extended to the 4-electron series isoelectronic with Be, namely B^+, C^{++}, ... and will be completed by the next semi-annual review.

The H_2O molecule calculations have been completed by the three center Hartree-Fock program and the results are being analyzed and written up for publication.

Two-Center, two-electron Coulomb integrals have been evaluated by the Fourier Convolution method and technique is being extended so as to handle exchange integrals and multicenter integrals. Other integral transform methods are also being investigated. A paper has been written recently discussing the atomic integrals needed for zero-field splitting calculations.

Elastic scattering states of H_2^- are being analyzed by a new theory and results are available in first of a series of papers in J. Chem. Phys. 42, 4063 (1965) June 15. The theory is based on the development of a quasi-variation principle.

Title PHOTOCHEMISTRY

NASA PROGRAM	SCIENCE TASK LEADER	DIRECTED TOWARD WHICH FLIGHT PROGRAM?
129	William B. DeMore Odell F. Raper	

BUDGET (K) | NASA Code: 129-02-03-02-55 | JPL Job. No. 329-21001-1-3260

	E	T	Total	Salary	Proc.	Total Direct	Total Green
FY '65	2	-	2	25	11	36	70
FY '66	2	.2	2.2	28	47	75	119

Total FY '66 Commitments to 1 September 1965 17

OBJECTIVE:

To acquire information on the chemistry of electronically excited atomic and molecular oxygen.

ABSTRACT:

An area of primary interest has been the chemistry of atomic oxygen in the ^1D electronic state. Topics emphasized in this program are reaction kinetics and mechanisms, the photo-production of $O(^1D)$ by ozone photolysis, and chemical mechanisms for deactivation of $O(^1D)$ to the 3P ground state.

Reactions previously studied include the three-body additions of $O(^1D)$ to N_2 and CO and the atom transfer reaction of $O(^1D)$ with O_3. To this list has now been added the reaction of $O(^1D)$ with CH_4, which is found to be very rapid and to have no activation energy.

The detailed mechanism involves three paths: a direct insertion of $O(^1D)$ into the C-H bond to give CH_3OH, a radical path giving CH_3 and OH as primary products, and a molecular path leading to CH_2O and H_2. Analysis of an observed scavenging effect of added oxygen has led to new information concerning the oxidation of the radicals CH_3 and OH.

New studies of O_3 photolysis, coupled with previous work, show that the $O(^1D)$ quantum yield is unity in the wavelength interval $2500Å < \lambda < 3000Å$ but falls to a value of 0.4 ± 0.15 in the 3130Å region. Photo-exchange experiments with labelled oxygen show that the total quantum yield of atomic oxygen, including $O(^1D)$ and $O(^3P)$, retains a constant value of unity throughout the wavelength range studied, with onset of $O(^3P)$ formation occurring at 3000Å. From the foregoing results the rate of $O(^1D)$ production in the lower atmosphere is calculated to be 1.2 ± 0.5 pphm/hr, based on an assumed O_3 concentration of 10 pphm and a solar zenith angle of 45^o.

Deactivation of $O(^1D)$ by N_2 and O_2 is of considerable interest to upper atmosphere chemistry. Certain of our laboratory findings have been extended by means of unimolecular and bimolecular reaction rate theory to evolve a chemical mechanism for deactivation of $O(^1D)$ involving transitory formation of excited adduct molecules such as N_2O^* and O_3^*. The high efficiency of N_2 as a deactivator which was predicted earlier on the basis of this theory now appears to have been substantiated by laboratory and upper atmospheric observations by other workers. As a continuation of this program we have shown by third body effects that deactivation of $O(^1D)$ by O_2 in the gas phase is now being studied by a technique involving O_3 photolysis in the presence of O_2 at pressures in the range 25 to 100 atm.

Internal Publications

1. "Primary Processes in Ozone Photolysis", Space Programs Summary No. 37-31, Vol. IV, 225 (1965).
2. "The Reaction of $O(^1D)$ with Methane", submitted for Space Programs Summary No. 37-35, Vol. IV.

External Publications

1. "Kinetics of Gas Phase Reactions", S. W. Benson and W. B. DeMore, Annual Review of Physical Chemistry, Vol. 16 (1965).
2. "The Reaction of $O(^1D)$ with Ozone," W. B. DeMore and O. F. Raper, submitted to J. Chem. Phys.
3. A paper entitled "Reaction of $O(^1D)$ from the Photolysis of Ozone" was presented by W. B. DeMore at the Sixth Informal Photochemistry Conference, University of California, Davis, California, June 15-17, 1964.

Title RADIATION CHEMISTRY

NASA PROGRAM	SCIENCE TASK LEADER	DIRECTED TOWARD WHICH FLIGHT PROGRAM?
129	Dr. James King, Jr.	

BUDGET (K) | NASA Code: 129-02-03-06 | JPL Job. No. 329-21301-1-3260

	E	T	Total	Salary	Proc.	Total Direct	Total Green
FY '65	1	0	1.0	14	11	25	45
FY '66	1	.2	1.2	15	31	46	70

Total FY '66 Commitments to 1 September 1965 6

OBJECTIVE:

To continue the investigation of gas-solid interactions including the radiation damage of solid surfaces. The results of theoretical investigations will be utilized in selecting appropriate gas-solid systems.

Gas Chromatography in conjunction with a 10,000 Curie Cobalt-60 γ-source will be used to study radiation damage of solid surfaces by noting the change in retention time on the column as a function of radiation dosage.

ABSTRACT:

A new electrostatic theory of gas-solid interaction has evolved from a study of the chromatographic separation of the hydrogen isotopes on an Al_2O_3 surface at low temperatures. The theory suggests that molecules are held to the surfaces of ionic (electronically charged) surfaces by unbalanced electrical fields of forces. By a detailed analysis of the gas-solid interactions one is able to predict the adsorptive behaviour of many gases on a variety of solid surfaces.

In the field of gas-solid chromatography, the theory aids in the search for new and improved adsorbents. The results of the theory

have been applied to the adsorption of the rare gases on an Al_2O_3 surface at room temperature. The prediction of the theory that the retention of the gases on the surface should be an exponential function of their molecular polarizabilities has been verified experimentally.

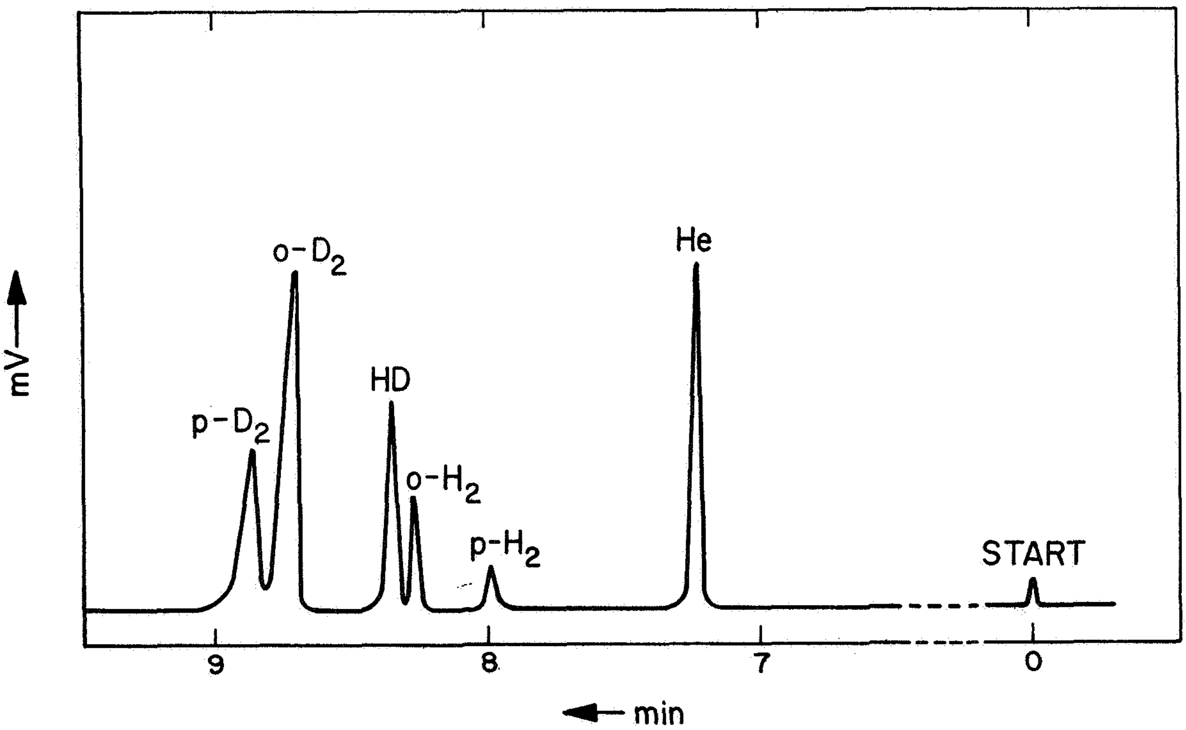
The theory offers strong support for the hypothesis that gas adsorption on zeolites (the so-called "molecular sieves") is similar to adsorption on other adsorbents. The results of the theory, when applied to the adsorption and separation of gases on synthetic zeolites, correctly predict the observed relationship between separability, adsorptivity and molecular polarizability. As a consequence of the new theory the previously held belief that gases separate on zeolites because of some type of "molecular sieve" action, has to be abandoned.

The electrostatic theory has also found application in the field of biology since the same type of physical adsorption observed on solid surfaces is believed to play a primary role in the mechanism of general anesthesia in the body. Anesthetic gases may be attracted from the blood plasma to a nerve cell by the electrostatic forces on the surface of the cell. The gas molecules literally blanket the cell, insulating it so that it can no longer transmit impulses to the brain. Since the theory suggests that the efficiency of a gas as an anesthetic is directly related to its polarizability, it is now possible to search for new, more efficient anesthetics with fewer unwanted side effects.

PUBLICATIONS

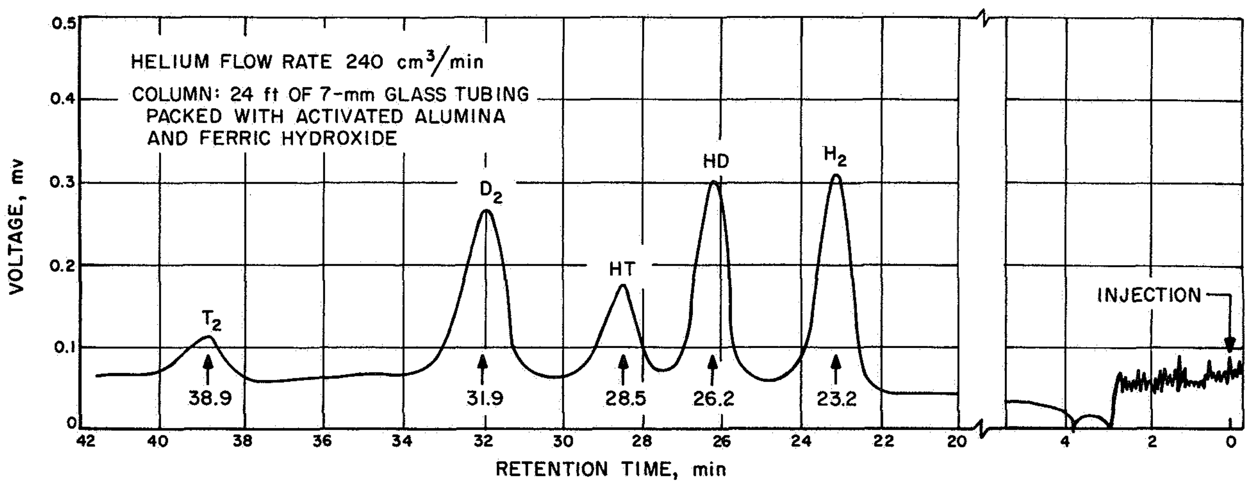
1. Separation of the Hydrogen Isotopes, J. King, JPL SPS 37-19, Vol. 4.
2. The Chromatographic Separation of the Hydrogen Isotopes Including Tritium, J. King, J. Phys. Chem. 67, 1397 (1963).
3. A Theory of Low Temperature Adsorption of Gases on Solids, J. King and S. Benson, J. Chem. Phys. 43 (1965).
4. Theory of the Low Temperature Chromatographic Separation of the Hydrogen Isotopes, J. King and S. Benson, JPL SPS 37-33, Vol. 4 (1965).
5. Electrostatic Aspects of Physical Adsorption with Some Applications for Molecular Sieves and General Anesthesia, J. King and S. Benson, Science (1965).
6. Electrostatic Interactions in Gas Solid Chromatography, J. King and S. Benson, Anal. Chem. 37 (1965).
7. The Separation of the Rare Gases in Accordance with Their Polarizabilities, J. King, Anal. Chem. 37 (1965).

RADIATION CHEMISTRY



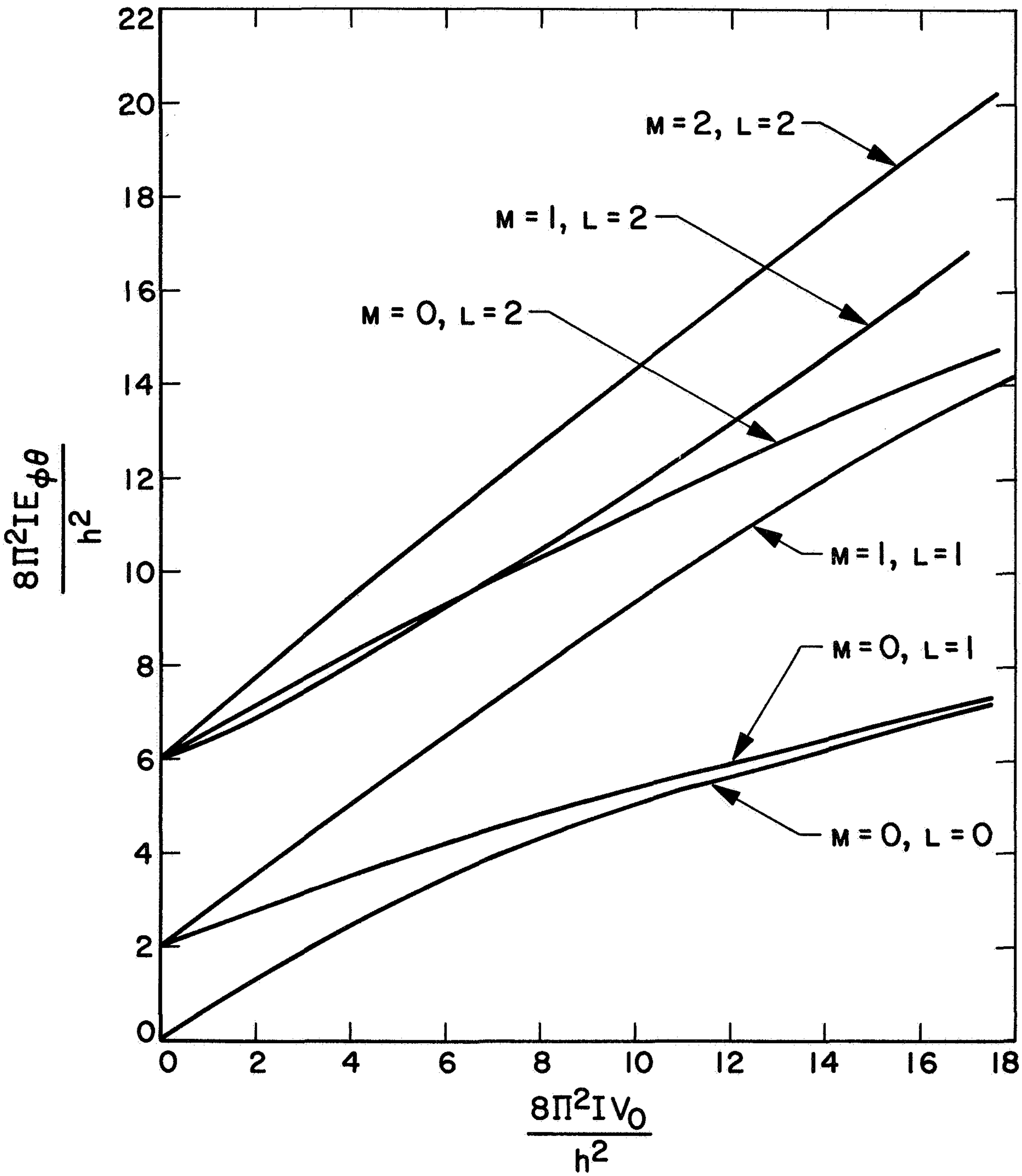
SEPARATION OF HYDROGEN ISOTOPES AND THEIR NUCLEAR SPIN ISOMERS. COLUMN LENGTH 80m; TEMPERATURE = 77.6° K; CARRIER GAS FLOW 2ml Ne/min; SAMPLE SIZE 1.5μl

RADIATION CHEMISTRY



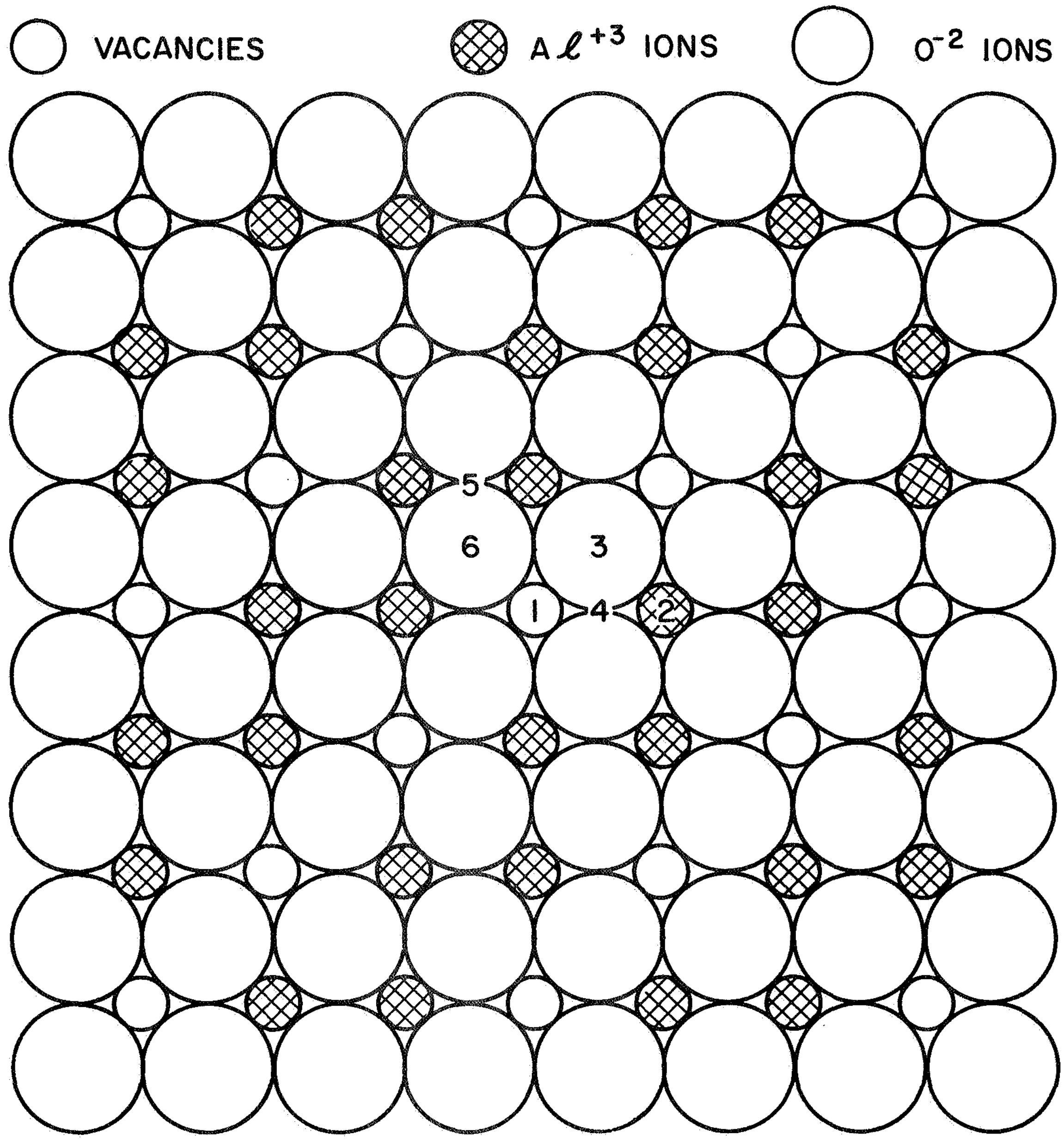
CHROMATOGRAM OF THE HYDROGEN ISOTOPES

RADIATION CHEMISTRY



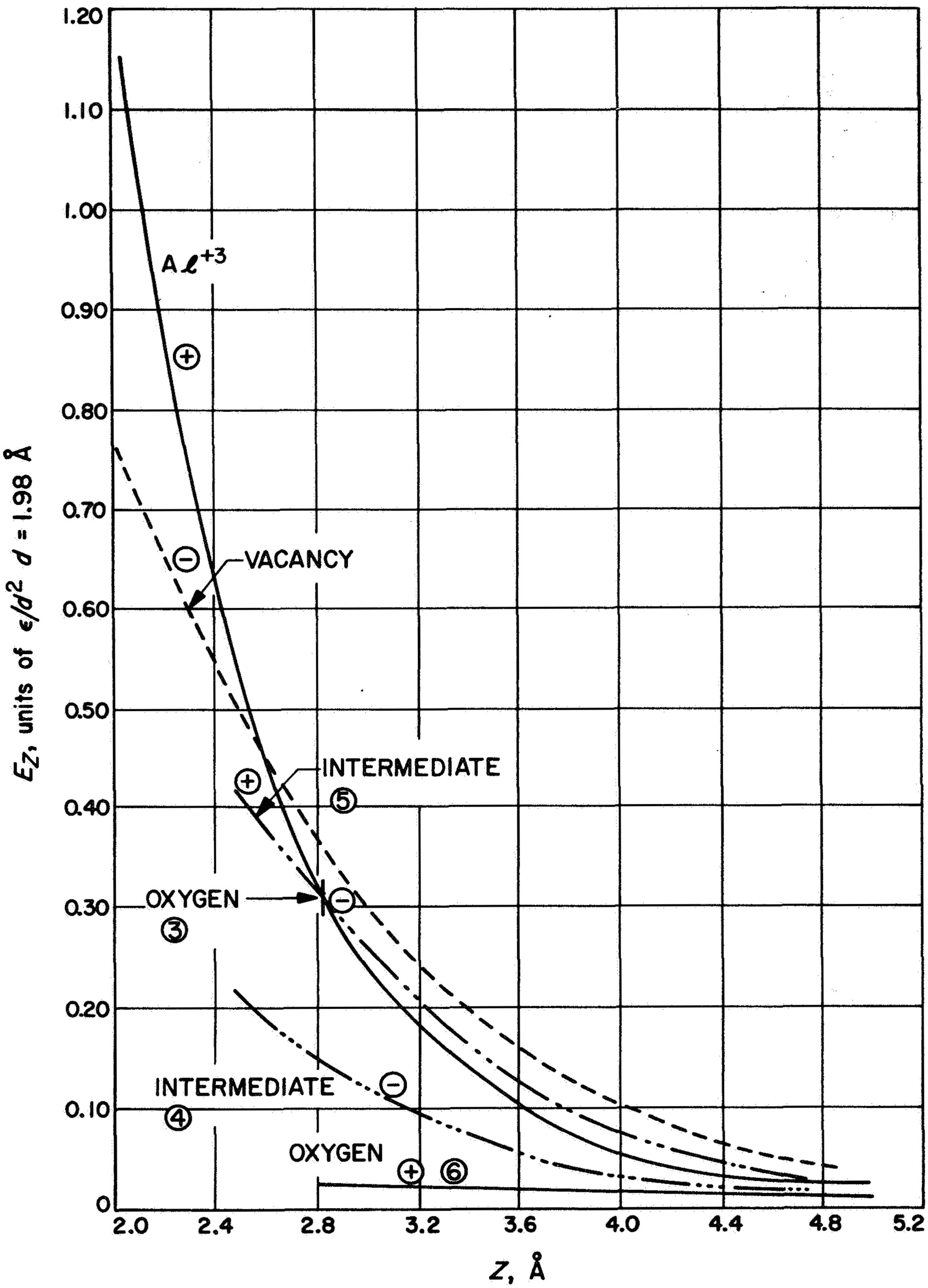
ROTATIONAL ENERGY vs BARRIER HEIGHT

RADIATION CHEMISTRY



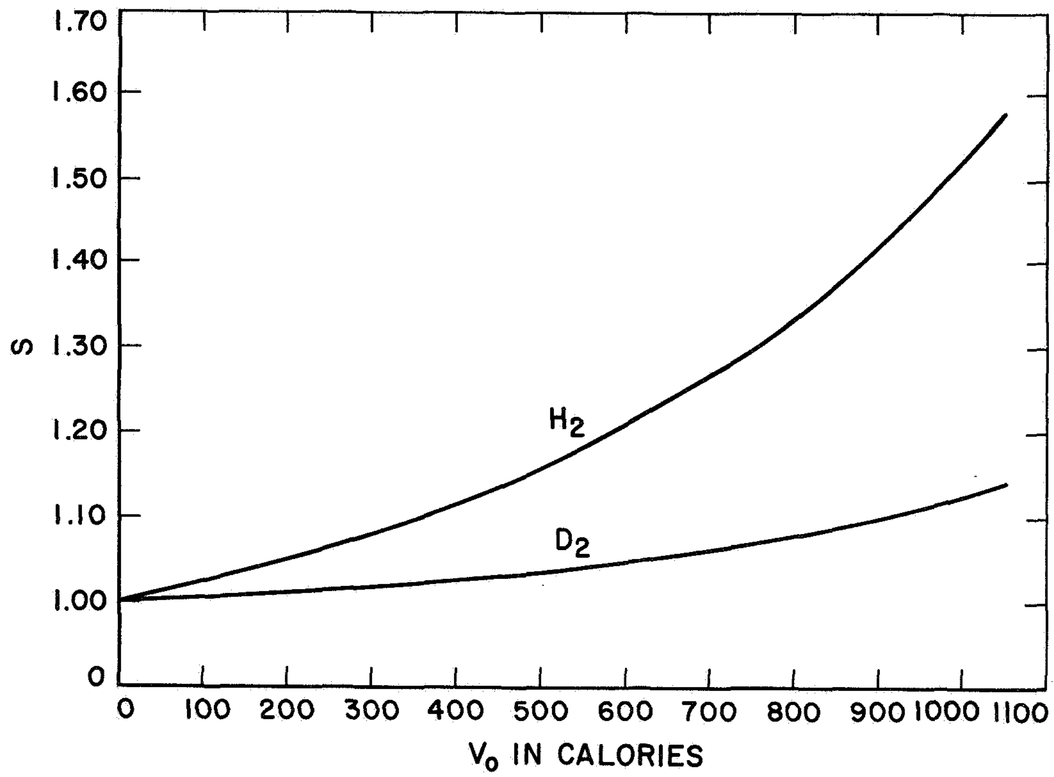
IDEALIZED MODEL OF Al_2O_3 STRUCTURE

RADIATION CHEMISTRY



COMPUTED FIELD INTENSITIES OVER DIFFERENT SITES ON SURFACE

RADIATION CHEMISTRY



ORTHO—PARA SEPARATION AS A FUNCTION OF BARRIER HEIGHT

RADIATION CHEMISTRY

CALCULATED SEPARATION FACTORS

	M and W Al_2O_3 - 77°K		M and S S_iO_2 - 77°K		SANDLER CHARCOAL - 77°K		KING Al_2O_3 - 77°K	
	$t_{r'}$ min	s	$t_{r'}$ min	s	$t_{r'}$ min	s	$t_{r'}$ min	s
$p\text{-}H_2$	4.27		0.644		---		7.26	
		1.22		1.391		1.1		1.15
$o\text{-}H_2$	5.23		0.895		---		8.35	
$o\text{-}D_2$	6.91		1.312					
		1.09		1.095				
$p\text{-}D_2$	7.51		1.438					

RADIATION CHEMISTRY
CALCULATED ENERGIES

	Al^{+3} SITES, $z = 2.47$ Å			VACANCY SITES, $z = 2.40$ Å		
	$m = 7$ $n = 9$	$m = 7$ $n = 12$	$m = 7$ $n = 15$	$m = 5$ $n = 9$	$m = 5$ $n = 12$	$m = 5$ $n = 15$
$-\Phi_o$	0.822	1.540	1.970	1.480	1.940	2.220
$E^{\nu}_{-H_2}$	0.297	0.470	0.595	0.375	0.497	0.595
E^{ν}_{-HD}	0.243	0.383	0.485	0.306	0.405	0.486
E^{ν}_{-HT}	0.210	0.332	0.420	0.265	0.352	0.421
$E^{\nu}_{-D_2}$	0.210	0.332	0.420	0.265	0.352	0.421
E^{ν}_{-DT}	0.188	0.297	0.376	0.237	0.314	0.376
$E^{\nu}_{-T_2}$	0.172	0.271	0.353	0.216	0.287	0.344

RADIATION CHEMISTRY

CALCULATED HEATS OF ADSORPTION

	Al^{+3} SITES, z = 2.47 Å			VACANCY SITES, z = 2.40 Å		
	m = 7 n = 9	m = 7 n = 12	m = 7 n = 15	m = 5 n = 9	m = 5 n = 12	m = 5 n = 15
$\Delta H_{p\text{-}H_2}$	0.333	0.878	1.185	0.913	1.251	1.433
$\Delta H_{o\text{-}H_2}$	0.489	1.034	1.339	1.069	1.407	1.589
ΔH_{HD}	0.457	1.035	1.373	1.052	1.413	1.612
ΔH_{HT}	0.501	1.097	1.439	1.104	1.477	1.688
$\Delta H_{o\text{-}D_2}$	0.472	1.068	1.410	1.075	1.448	1.658
$\Delta H_{p\text{-}D_2}$	0.600	1.196	1.538	1.203	1.576	1.787
ΔH_{DT}	0.514	1.123	1.474	1,123	1.506	1.724
$\Delta H_{p\text{-}T_2}$	0.552	1.171	1.479	1.166	1.565	1.778
$\Delta H_{o\text{-}T_2}$	0.616	1.235	1.543	1.230	1.629	1.842

RADIATION CHEMISTRY

			$o-H_2$	HD	$o-D_2$	$p-D_2$
	$p-H_2$					
$\Delta H(Al_2O_3)$ (Kcal/mole)	obs	1.40	1.55	1.51	1.58	1.65
	calc (5-12)	1.25	1.41	1.41	1.45	1.58
$\Delta H(SiO_2)$ (Kcal/mole)	obs	0.77	0.93	0.92	1.00	1.09
	calc (7-12)	0.88	1.03	1.04	1.07	1.20
	calc (5-9)	0.91	1.07	1.05	1.08	1.20

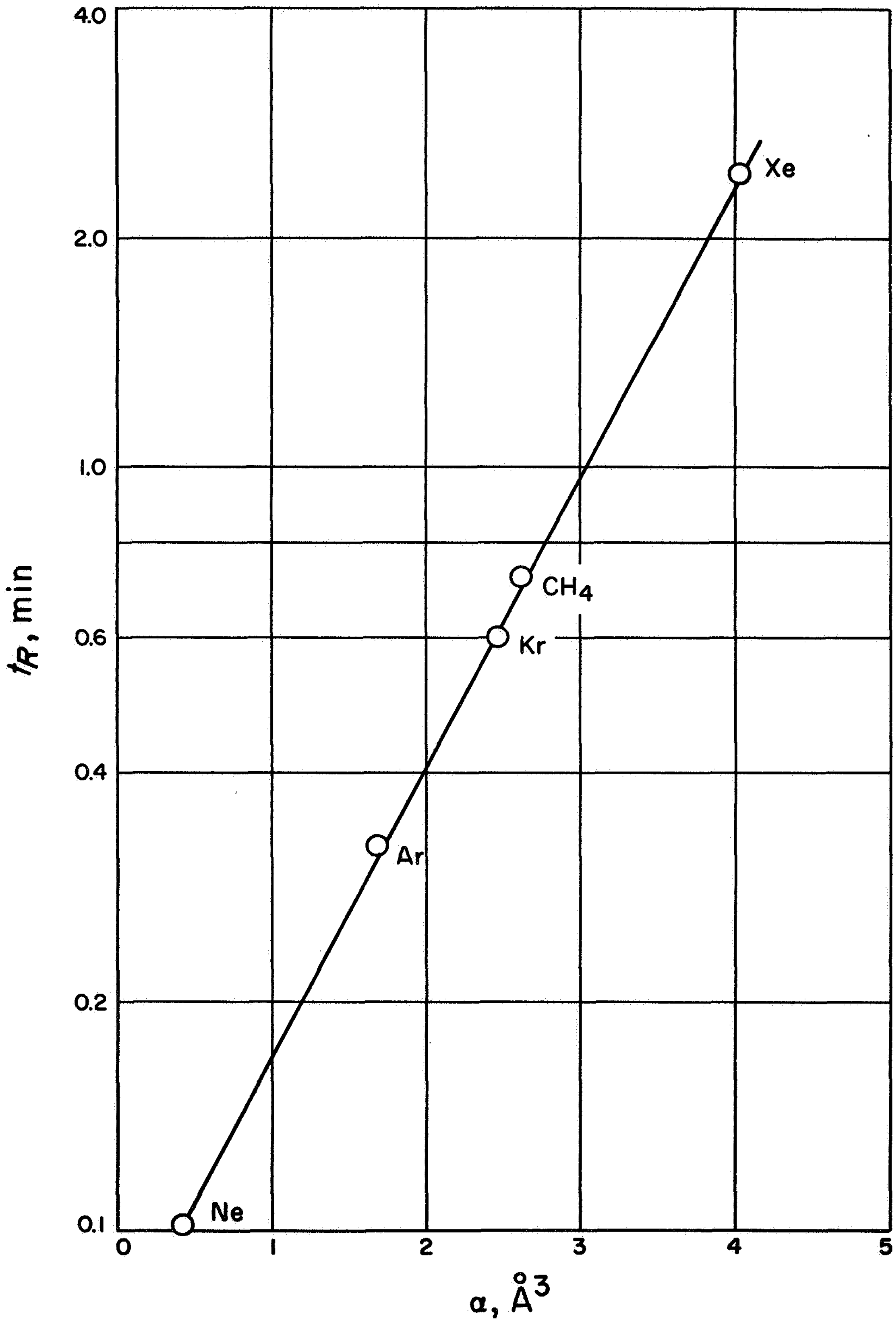
A COMPARISON OF EXPERIMENTAL AND CALCULATED HEATS OF OXYGEN

RADIATION CHEMISTRY

A COMPARISON AT EXPERIMENT AND CALCULATED SEPARATION FACTORS

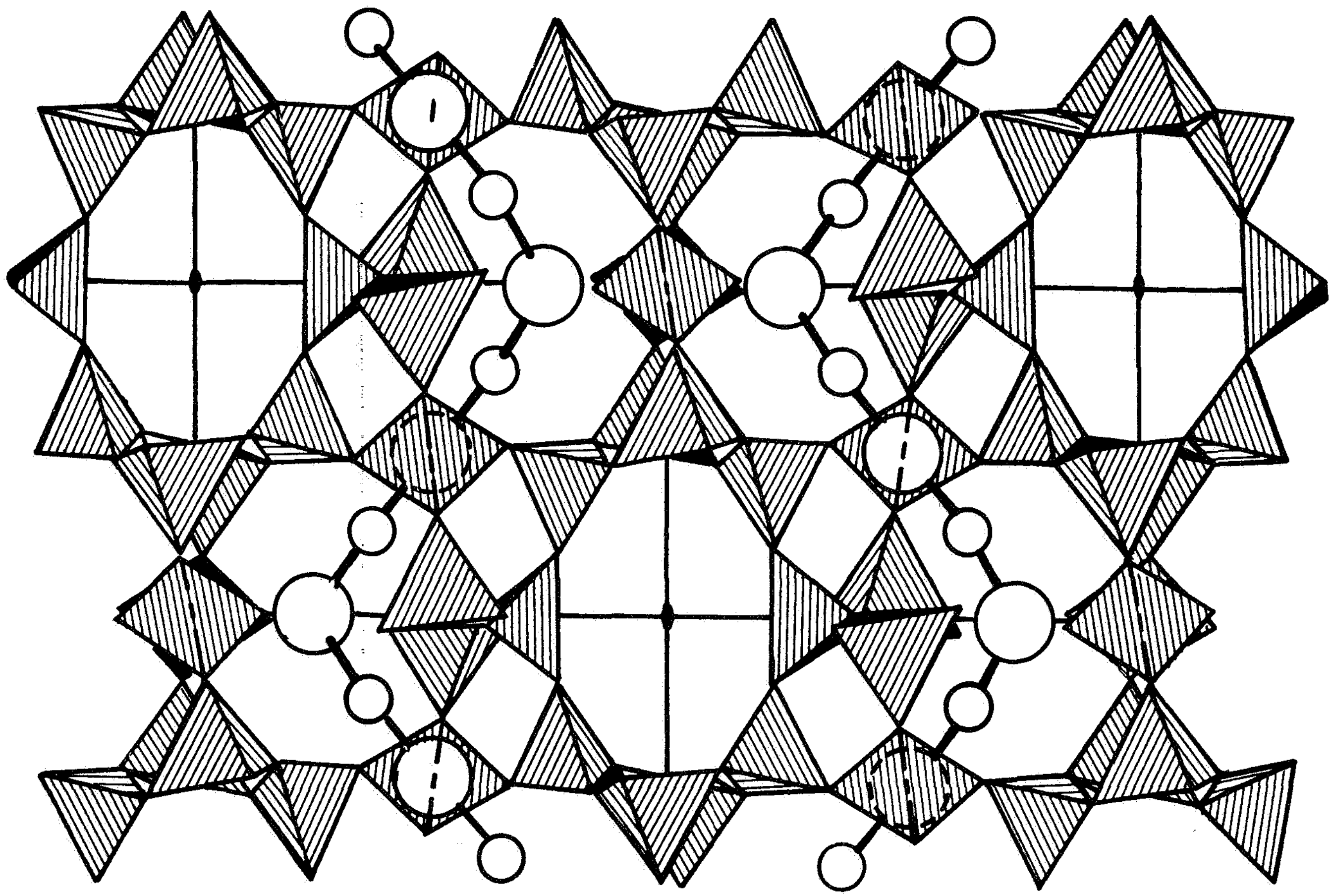
	S_i (exp) KING t_i/t_{H_2}	S_i (exp) C and S t_i/t_{H_2}	S_i (exp) M and W t_i/t_{H_2}	S_i (calc) m=5, n=9 t_i/t_{H_2}	S_i (calc) m=5, n=12 t_i/t_{H_2}
e-H_2	1	1	1	1	1
HD	1.14	1.22	1.09	1.31	1.50
HT	1.23	1.42	1.20	1.52	1.92
e-D_2	1.38	1.49	1.26	1.70	2.15
DT	---	1.85	1.45	2.05	2.75
e-T_2	1.68	2.08	1.66	2.10	2.93

RADIATION CHEMISTRY



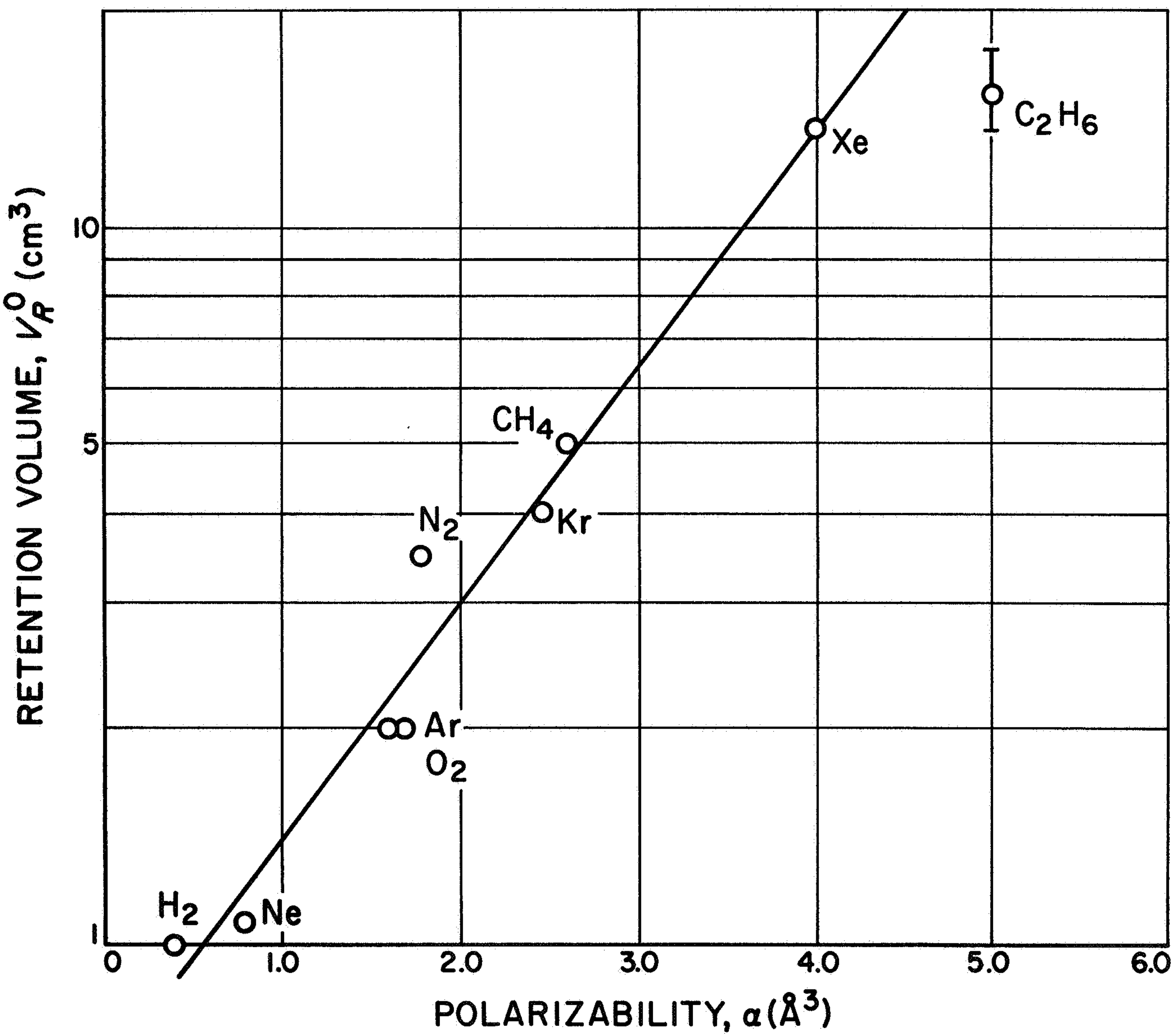
THE SEPARATION OF RARE GASES ON AN Al_2O_3 COLUMN AS A FUNCTION OF THEIR POLARIZABILITIES

RADIATION CHEMISTRY



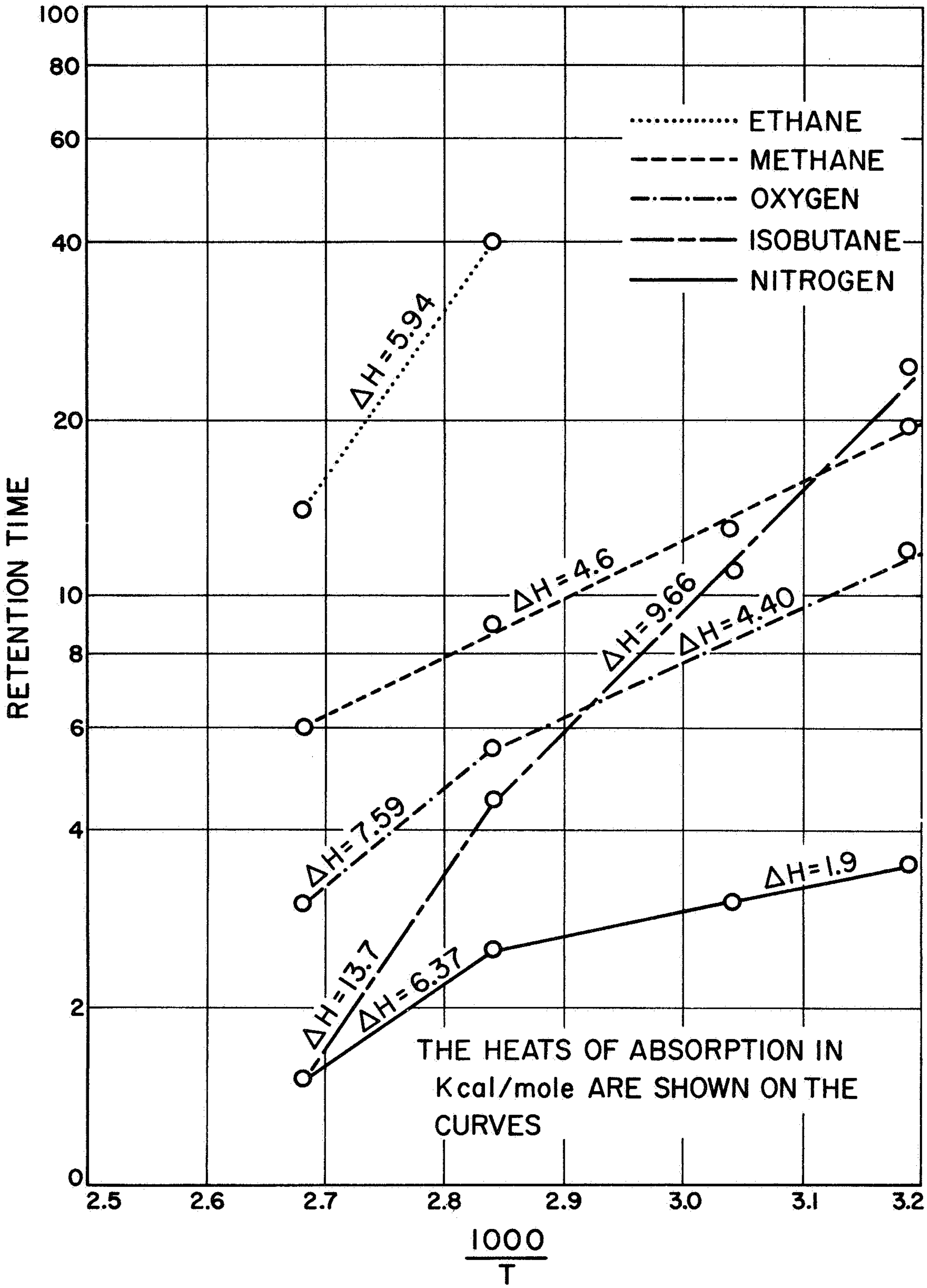
STRUCTURE OF ANALCITE PROJECTED INTO THE (100) PLANE

RADIATION CHEMISTRY



THE RELATIVE RETENTION VOLUMES ON LINDE 5A MOLECULAR SIEVE COLUMN AS A FUNCTION OF THE MOLECULAR POLARIZABILITIES

RADIATION CHEMISTRY



RETENTION TIMES ON 5A MOLECULAR SIEVE AS A FUNCTION OF TEMPERATURE

Title Plasma Physics Research

NASA PROGRAM	SCIENCE TASK LEADER	DIRECTED TOWARD WHICH FLIGHT PROGRAM?
129	Dr. A. Bratenahl	

BUDGET (K) **NASA Code:** 129-02-03-03-55 **JPL Job. No.** 329-20701-1-3270

	E	T	Total	Salary	Proc.	Total Direct	Total Green
FY '65	2.8						178
FY '66	1.3	1.0	2.3	24	80	104	142

Total FY '66 Commitments to 1 September 1965 13

OBJECTIVE:

Plasma Dynamics, particularly processes of motion in magnetic fields, are basic to solar flare and other processes by which the sun effects the interplanetary medium. We are investigating experimentally the validity of certain current theories relating to fast relinking of flux and the possible relation of magnetic neutral points to solar flares. The neutral point is produced in a double inverse pinch experiment.

In late FY 66 a switch-on dipole experiment will be initiated to investigate the invasion of a magnetized plasma by a dipole field.

ABSTRACT:

It is well known that neutral points and lines play an essential role in hydromagnetics on the astrophysical scale. While the subject has received considerable theoretical attention (for example, theories of solar flares), Ref. 1, we believe this is the first experimental study conducted for this specific purpose. The experiment consists of two inverse pinch devices mounted side by side in a common vacuum chamber, Fig. 1. We observe the collision of two magnetically-driven cylindrical shocks. Properties of the inverse pinch have been studied by others, Refs. 2 and 3, and seem well

ABSTRACT (CONT.): Plasma Physics Research

understood. The shocks produced follow the simple "snow plow" model reasonably well.

It should be made clear, however, that even when the gas is well ionized ahead of the shock, the magnetic piston is "leaky," and highly conducting plasma exists in the region behind the piston. It is precisely the region behind the "piston" that is of interest in this experiment, and we can estimate from its behavior that the magnetic Reynolds number is much greater than one. This is large enough to permit making some analogies on the astrophysical scale.

With a Kerr-cell camera of 0.2 μsec open-time, one can produce single frames of the shock propagation and collision which may be fitted together to form a rather convincing kinematic presentation, Fig. 2. One-half period of the driving current is 20 μsec. The fronts collide at 4 μsec, moving at a velocity of 1.2 cm/μsec. The interface between the expanding cylinders flattens into a brilliant sheet during the first 4 μsec, suggesting the formation of a sheet pinch, which is then followed by a thinning and darkening in the central portion, suggesting the formation of a neutral point and flux relinking. Subsequently, the two flattened cylinders merge into a single expanding oval about 13 μsec, just past current maximum.

With this background of pictorial data, a double magnetic probe was introduced. The probe is a 3-mm OD quartz tube closed at the end, inside of which are mounted two 10-turn coils, one inside the other, with their axes at right angles. By integrating the voltages induced in these coils, ABSTRACT (CONT.)   Plasma Physics Research

the component fields B_x and B_y are determined. The component fields are plotted on a polar diagram from which the magnitude and direction of the local field can be plotted as functions of time, Fig. 3.

The results came as a considerable surprise. The time dependence of the field angle, Fig. 4, clearly demonstrates that the flux relinking takes place intermittently (with a period of approximately 2 μsec) during the first quarter-cycle. The exact phase and magnitude of each event varies from shock to shock, characteristic of the operation of instabilities. It seems one possible explanation for this result is that we are dealing with oscillations between two distinct magnetic configurations, Fig. 5: (1) a sheet pinch or collision layer of large current density separating antiparallel fields; (2) an x-type neutral line with considerably reduced current density across which magnetic flux is being rapidly relinked.

According to Furth, Killeen, and Rosenbluth, Ref. 4, the sheet pinch, Configuration (1), is unstable (finite resistive tearing mode) to the formation of a neutral point, Configuration (2). The relinking of flux at the neutral point can proceed much faster than by simple resistive diffusion through the cooperation of a pair of switch-off shock waves, according to Petschek, Fig. 6, Ref. 1, p. 425. On the other hand, according to Dungey, Ref. 5, Chapman and Kendall, Ref. 6, and Uberoi, Ref. 7, Fig. 7, an x-type neutral point, Configuration (2), is hydromagnetically unstable to the formation of a sheet pinch. Thus the two observed states are each unstable to the formation of the other. During the time energy is flowing into the system (first-quarter cycle), we observe as many as four "flip-flops" between these states.

ABSTRACT (CONT.): Plasma Physics Research

This somewhat unexpected behavior of a neutral point in a plasma is, of course, only a particular resolution of an interesting configurational conflict (a steady-state solution may be possible and is hinted at in a paper by Green, Ref. 8, in a treatment of our configuration. Green's estimate of the time scale satisfies requirements for solar flares). It is interesting to speculate if the ambiguous and conflicting observed magnetic behavior of solar flares might be due to a flip-flop process such as this. For instance, repeating flares (often called homologous flares) are described by Parker, Ref. 9, as "following some blueprint that is characteristic of the site" which "does not seem to be destroyed by the individual flares."

To establish the details of what is occurring will require the measurement of the vector fields at two points simultaneously, so that the local curl of B may be determined. Of greater significance at this stage in the investigation will be a search for runaway electrons and X-rays from the pinch and accelerated plasma jets from the fast relinking process, correlating these events with the magnetic behavior. One might also expect rapid changes in spectral line widths due to Stark and Doppler broadening. It is hoped to obtain a fast-framing camera to study the detailed morphology in a single shock (Kerr-cell photography of single frames provided very little hint of the fast changes actually taking place).

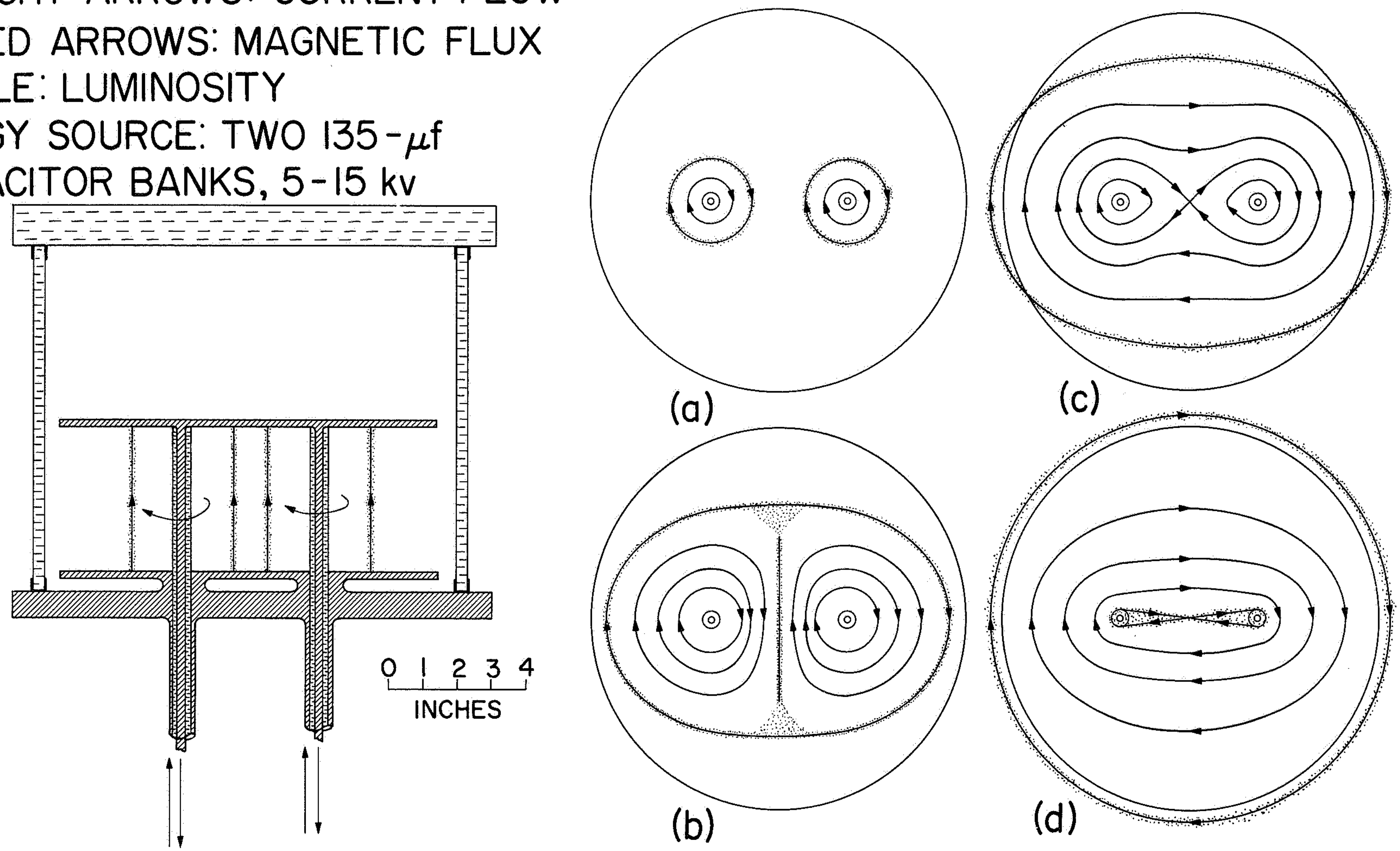
ABSTRACT (CONT.): Plasma Physics Research

References

1. Various authors, Physics of Solar Flares, NASA SP 50, 1963.
2. Vlases, George C., Physical Review Letters, Vol. 12, p. 43, 1964.
3. Johansson, Rolf B., The Physics of Fluids, Vol. 8, p. 866, 1965.
4. Furth, H. P., Killeen, J., and Rosenbluth, M. N., The Physics of Fluids, Vol. 6, p. 459, 1963.
5. Dungey, J. W., Cosmic Electrodynamics, Cambridge University Press, 1958.
6. Chapman, S., and Kendall, P. C., Proceedings of the Royal Society (London), Vol. 271, p. 435, 1963.
7. Uberoi, M. S., The Physics of Fluids, Vol. 6, p. 1379, 1963.
8. Green, R. M., Stellar and Solar Magnetic Fields, IAU Symposium No. 22, North Holland Publishing Co. (1965), p. 398.
9. Parker, E. N., Astrophysical Journal, Supplement Series 77, 8: 177, 1963.
10. Severny, A. B., Astronomical Journal (USSR), No. 37, p. 609, 1960.

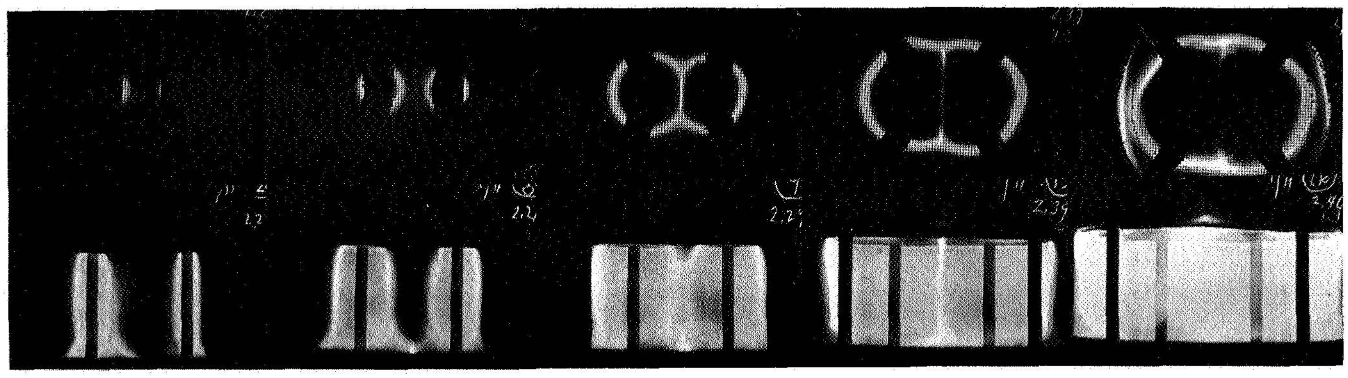
PLASMA PHYSICS

STRAIGHT ARROWS: CURRENT FLOW
CURVED ARROWS: MAGNETIC FLUX
STIPPLE: LUMINOSITY
ENERGY SOURCE: TWO 135-μf CAPACITOR BANKS, 5-15 kv



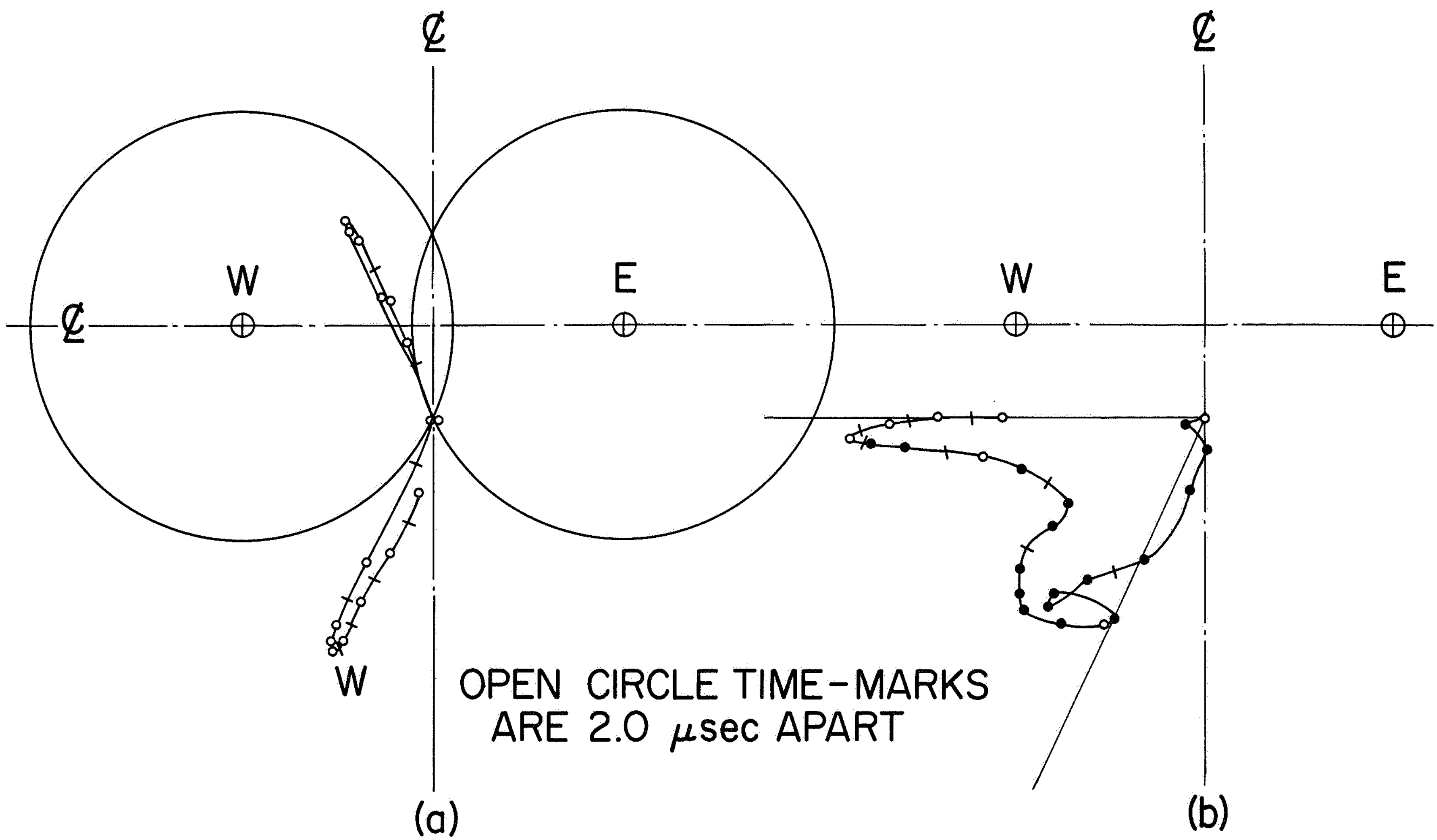
DOUBLE INVERSE PINCH:
(a) BEFORE COLLISION; (b) AFTER COLLISION; (c) CURRENT MAXIMUM; (d) FIRST CURRENT ZERO

PLASMA PHYSICS



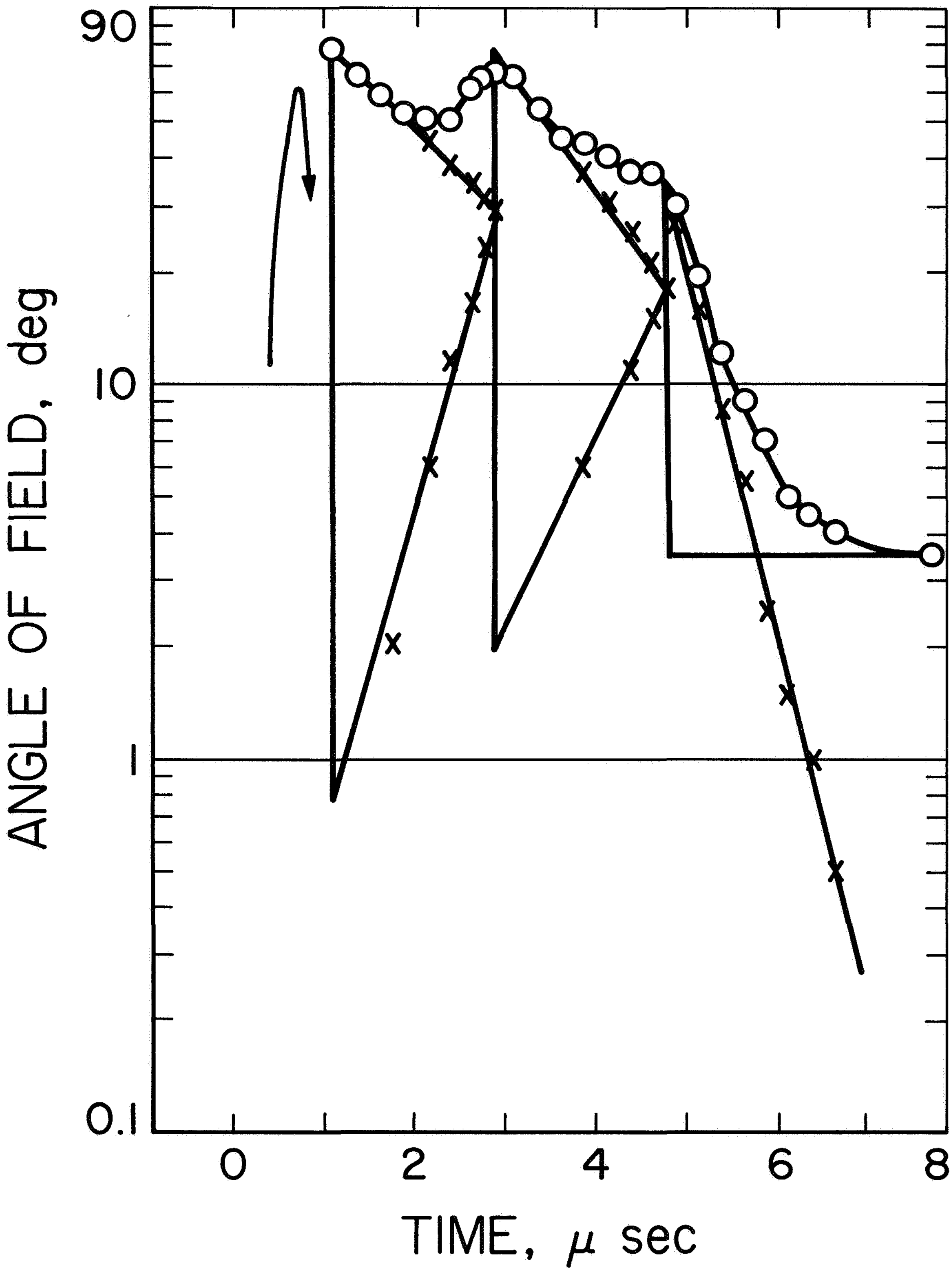
TIME INTERVAL BETWEEN FRAMES, 1.5μsec

PLASMA PHYSICS



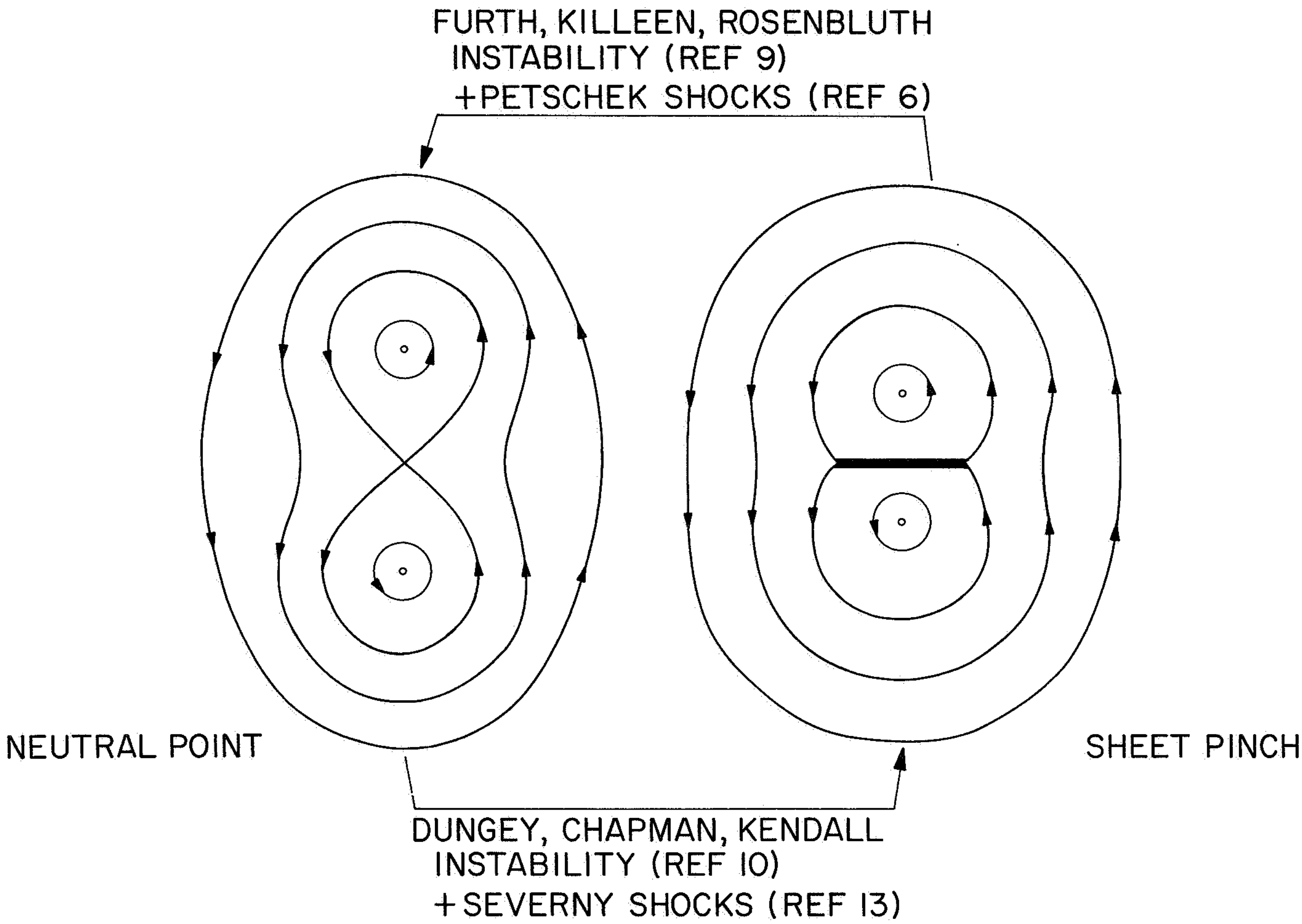
MAGNETIC PROBE DATA:
(a) POLAR PLOT OF EAST AND WEST BANK SEPARATELY
(b) BEHAVIOR AT POINT SLIGHTLY TO WEST OF ELECTRICAL MID-PLANE AFTER COLLISION OF TWO SHOCKS

PLASMA PHYSICS



TIME DEPENDENCE OF DIRECTION OF MAGNETIC FIELD AND ITS RESOLUTION INTO COMPONENTS SHOWING POSSIBLE EXISTENCE OF COMPETING PROCESSES

PLASMA PHYSICS

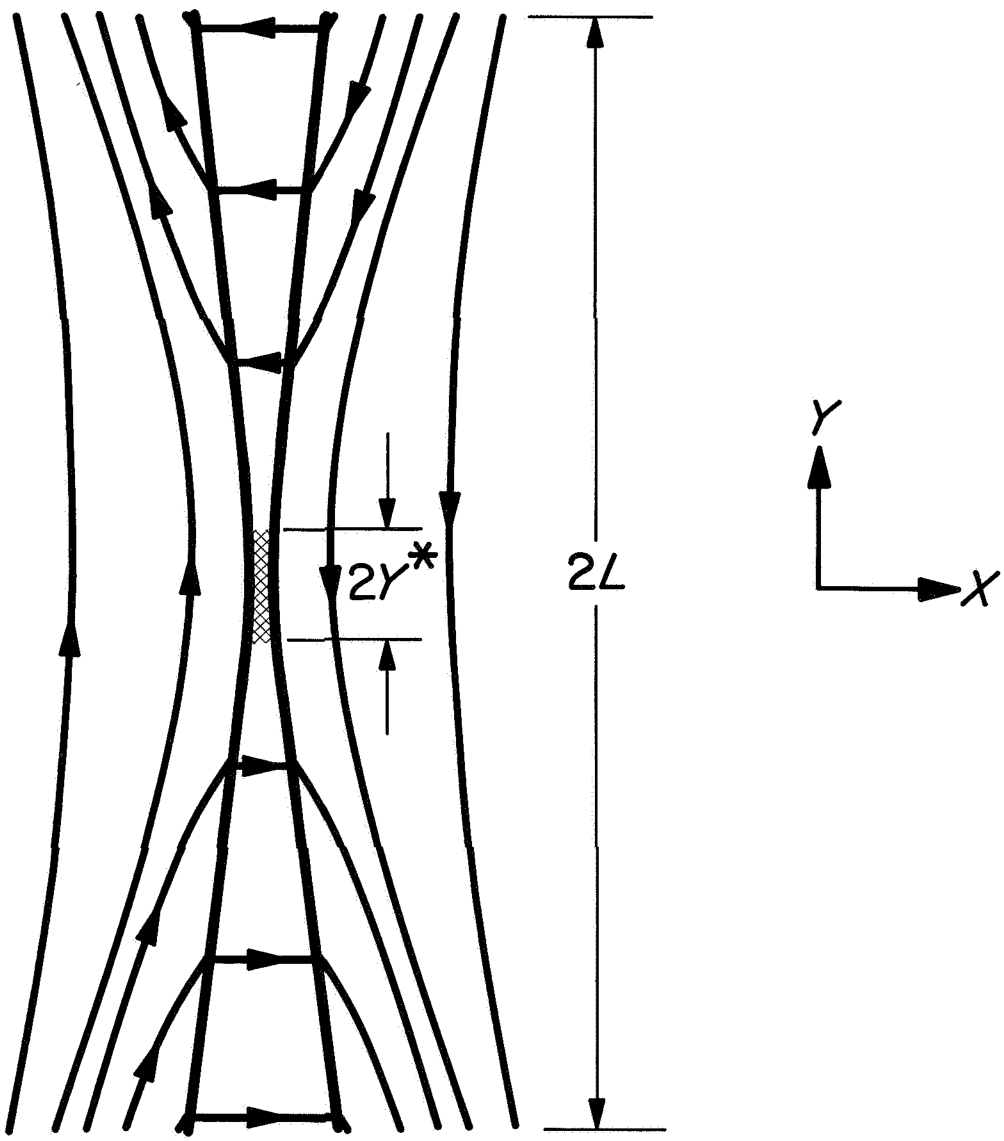


THE PETSCHEK AND SEVERNY SHOCKS HAVE AT PRESENT ONLY A THEORETICAL BASIS

FLIP-FLOP BETWEEN THESE CONFIGURATIONS OCCURS 3 TO 4 TIMES DURING FIRST QUARTER-CYCLE

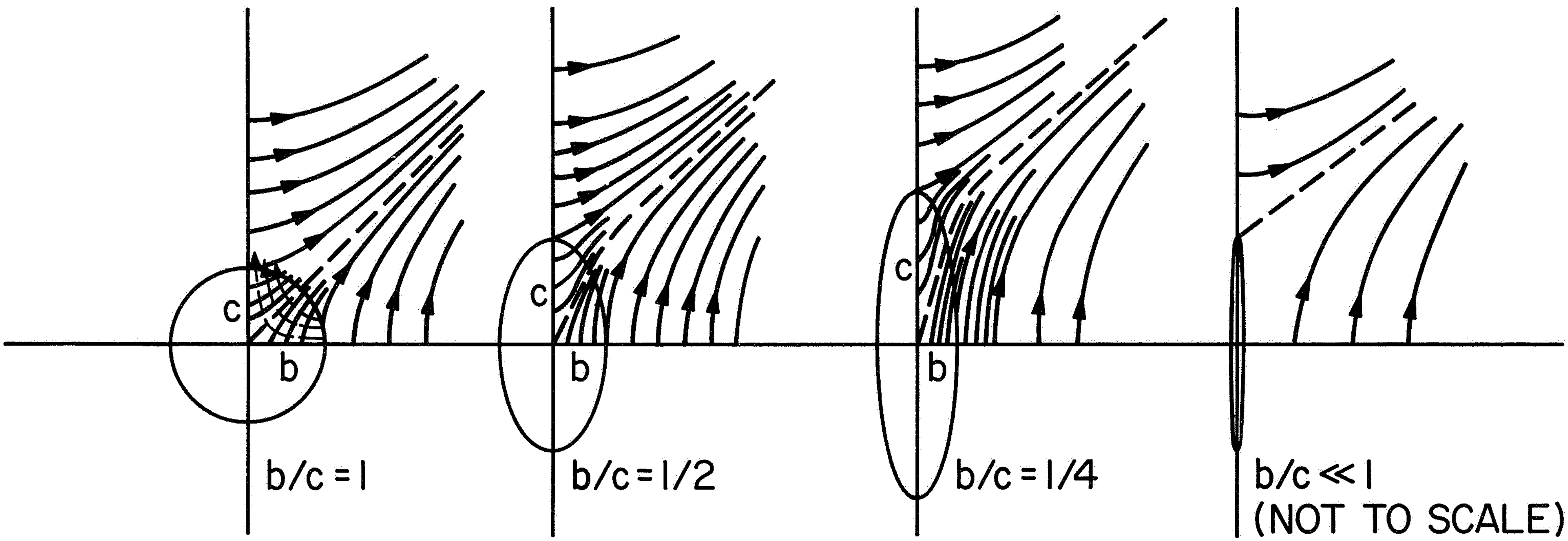
TWO MAGNETIC CONFIGURATIONS EACH UNSTABLE TO FORMATION OF THE OTHER

PLASMA PHYSICS



FAST FLUX RELINKING PROCESS ACCORDING TO PETSCHEK.
HEAVY LINES ARE ALFVÈN WAVES

PLASMA PHYSICS



DISTORTION OF CONDUCTING FLUID CYLINDER AT A MAGNETIC NEUTRAL POINT, ACCORDING TO CHAPMAN AND KENDALL

Title Low Temperature Physics

NASA PROGRAM	SCIENCE TASK LEADER	DIRECTED TOWARD WHICH FLIGHT PROGRAM?
129	D. D. Elleman (A. F. Hildebrandt)	

BUDGET (K) | NASA Code: 129-02-05-04-55 | JPL Job. No 329-20401-1-3280

	E	T	Total	Salary	Proc.	Total Direct	Total Green
FY '65*	2.3	0.9	3.2	41	82	129	185
FY '66	1.2	1.0	2.2	26	55	81	121

Total FY '66 Commitments to 1 September 1965 30

OBJECTIVE:

To measure and understand a variety of fundamental low temperature phenomena. Current emphasis: magnetic fields produced by rotating and nonrotating superconductors in zero or small applied field; attempts to achieve and measure absolute zero field; high-resolution multiple-irradiation nuclear-magnetic-resonance studies; high-magnetic-field phenomena in superconductors; and study of the Fermi surface of selected metals using the de Haas-Van Alphen effect.

*This task is a contraction of two FY 65 tasks, Low Temperature Physics and High Field Superconductivity.

ABSTRACT:

Low Field Superconductivity

Work has continued on the study of magnetic fields produced by rotating and nonrotating superconducting cylinders and cylindrical shells in zero and small applied magnetic fields (approximately 20 γ). These experiments are a continuation of the study of the London moment that has been successfully measured at this laboratory and reported in the literature.[1,2,3] It has been found that nonrotating superconducting lead cylindrical shells produce persistent fields as large as 100 γ

when the shells are made to go superconducting in a zero (less than one gamma) applied field. The magnitude of the persistent or trapped field is of a random nature, and the field may be either positive or negative. Also small applied external axial fields have no measurable effect on the magnitude or sign of the trapped field. It has also been observed that the trapped field is quite non-uniform and can have relatively large nonaxial components (approximately 20 γ or less).

Thermal switches have been added to the superconducting shells in order that a section of the shell may be driven normal and the persistent current interrupted.

Figure 1 shows such a switch mounted on a superconducting cylinder. It was found that when the thermal switch was activated fields of 100 γ or less could be produced and trapped with zero applied external field. It was found also that very nearly the same field was trapped each time the switch was activated, so long as the position of the switch was not changed. When the position of the switch was changed a new value of trapped field was observed, and it was impossible to predict the value of this new field. It is believed that thermal gradients is the superconductor are responsible for producing the persistent currents and fields. Experiments have been conducted with superconducting lead solenoids in a manner similar to that described above, and comparable fields have been observed. The results from the superconducting solenoid experiments tend to confirm the hypothesis that thermal gradients produce the persistent currents and fields in the superconducting material.

Understanding these thermal gradient effects is an important step toward the goal of producing absolute zero fields.

De Haas-Van Alphen Studies

Work on the study of the Fermi surface of metals using the de Haas-van Alphen (dHvA) effect has continued. With the availability of a high-field superconducting magnet (50 kilogauss) and a 100-kilogauss Bitter-type magnet at the laboratory, it was decided to use a modulated field magnetometer for the study of the dHvA effect. A new method for the analysis of the complex wave form from the dHvA experiments has been developed at this laboratory.[4] This new method of analysis has two important features:

(1) It yields directly the frequencies and amplitudes of all the component waves in the experimental wave form.

(2) It effectively improves the signal-to-noise ratio of the experimental system.

Briefly, the method consists of FM-recording the raw data from the modulated field magnetometer with a magnetic-tape recorder. The data is then digitized so that it may be fed to a digital computer where a Fourier analysis (using 1/H in place of time) is performed. The computation is performed by taking the Fourier transform of the auto-correlation function. Since this is an integrative process, the signal-to-noise ratio improves as the length of the run is increased. The computer output is a plot of mean-squared voltage versus frequency and shows sharp peaks at all dHvA frequencies. Preliminary results with tin show the three highest frequency peaks for the [001] field direction. The sharpest peak has a resolution of 5%. The modulated-field magnetometer with detection at the second harmonic frequency is used to obtain the raw dHvA data. Figure 2 is a schematic diagram of the system. Field modulation is derived from the 14-Kc oscillator.

The harmonic content of the oscillator signal is reduced by the low-pass filter. Following filtering, the signal is amplified by a low distortion power amplifier and applied to the modulation coil around the sample in the 50-kG superconducting magnet. A second harmonic signal is produced by the sample because of the non-linear relationship between the applied field and the sample magnetization. The signal from the detection coil is passed through a 28-Kc band-pass filter to attenuate the 14-Kc component and then is amplified and finally rectified following synchronous detection. The rectified signal, which exhibits the dHvA oscillation of the form

$$V\left(\frac{1}{B}\right) = \sum_n A_n(B) \sin(2\pi F_n \frac{1}{B} + \Gamma_n)$$

as the magnetic field is slowly swept, is FM recorded on magnetic tape for subsequent computer analysis. A detailed view of the dewar, sample holder and detection coils is shown in Fig. 3.

Work is now in progress to improve the computer program so that a finer grain mesh is used in sampling the data. This will improve the resolution of the program and allow us to look for higher frequency dHvA oscillations. We plan to do a dHvA study of a niobium crystal that we have already purchased and mounted. With the increased sensitivity of our magnetometer it is believed we will be able to observe and measure the dHvA oscillations in niobium and thus obtain some of the first information on the size and shape of the Fermi surface of this element. We also plan to restudy other crystals that have been looked at in the past but with lower resolution magnetometers. We should be able to pick up small amplitude oscillations that have been missed in the past.

Nuclear Magnetic Resonance

The nuclear magnetic resonance experiments have progressed along two distinct and separate courses:

(1) high-resolution multiple-irradiation nuclear magnetic resonance studies

(2) wide line nuclear magnetic resonance studies of soil and rock sample.

The multiple-irradiation studies are designed so that complicated NMR spectra may be simplified and studied by irradiating certain portions of the spectrum with high intensity irradiation. In addition, the relative signs of spin coupling constants are obtained by the new technique of "tickling."

A look at the energy level diagram (shown in Fig. 4) of a three-spin system will give a better understanding of how a tickling experiment determines the relative signs of the spin system. The NMR experiments are typically performed in a field of 14 Kg at 60 mc with line width of transitions of 0.1 cps or 0.02 milligauss. Therefore in order to irradiate a particular transition in the spectrum and simultaneously observe other transitions it is necessary to control the frequency of the spectrometer and the magnetic field to one part in 10^9. Figure 5 shows a diagram of the field lock system that we are now employing at this laboratory.[5] This particular field lock system controls the field-frequency setting of the order 1-2 parts in 10^{10} for periods up to 30 minutes and one part in 10^9 for 24 hours.

Figure 6 shows the rather complicated spectrum of propylene oxide that has been analyzed with the aid of the present spectrometer. Figure 7 is a portion of the energy level diagram associated with line 1 and Figure 8 shows the results of a tickling experiment performed on transition 1. From this particular experiment we learn that J_{AD} is a different sign from J_{CD}, and that J_{AB} is of the same sign as J_{BC}. Figure 9 shows the energy level diagram for the D_3 transitions with ABC spin states of $\beta\beta$ (heavy arrows) and their associated A, B and C transitions. Figure 10 shows the spectrum of the A and B proton of propylene oxide with line 65 irradiated. In a manner similar to this, other complicated spectra have been analyzed which yield results on proton-proton spin coupling constants[6] as well as coupling constants with other nuclei.[7]

The second area of nuclear magnetic resonance studies is the investigation of water content of rock and soil samples. The reasons for the interest in this area of research are:

(1) The amount and nature of water present in lunar and planetary soils and rocks may be suggestive of the possibility of the existence of some form of extra-terrestrial life.

(2) Such water is interesting from a geological standpoint.

(3) It may indicate something concerning the planetary or lunar surface chemistry.

(4) It may be a critical factor in design of life-support systems for manned bases.

Proton nuclear magnetic resonance (NMR) offers many advantages over other conventional techniques of measuring water content of soil samples. The primary advantage is that NMR is non-destructive method of measuring water content. Figure 11 is a summary of results of measurements taken on some terrestrial rock and soil samples.[8] Figure 12 shows a flight type instrument that is now being studied to determine sensitivity and accuracy of a simple transistor type spectrometer.

References and List of Recent Publications

1. A. F. Hildebrandt, Phys. Rev. Letters 12, 190 (1964).
2. A. F. Hildebrandt, Proceedings of the IXth International Conference of Low Temperature Physics (Columbus, Ohio)(In press).
3. A. F. Hildebrandt, D. D. Elleman, JPL SPS 37-34, Vol. IV.
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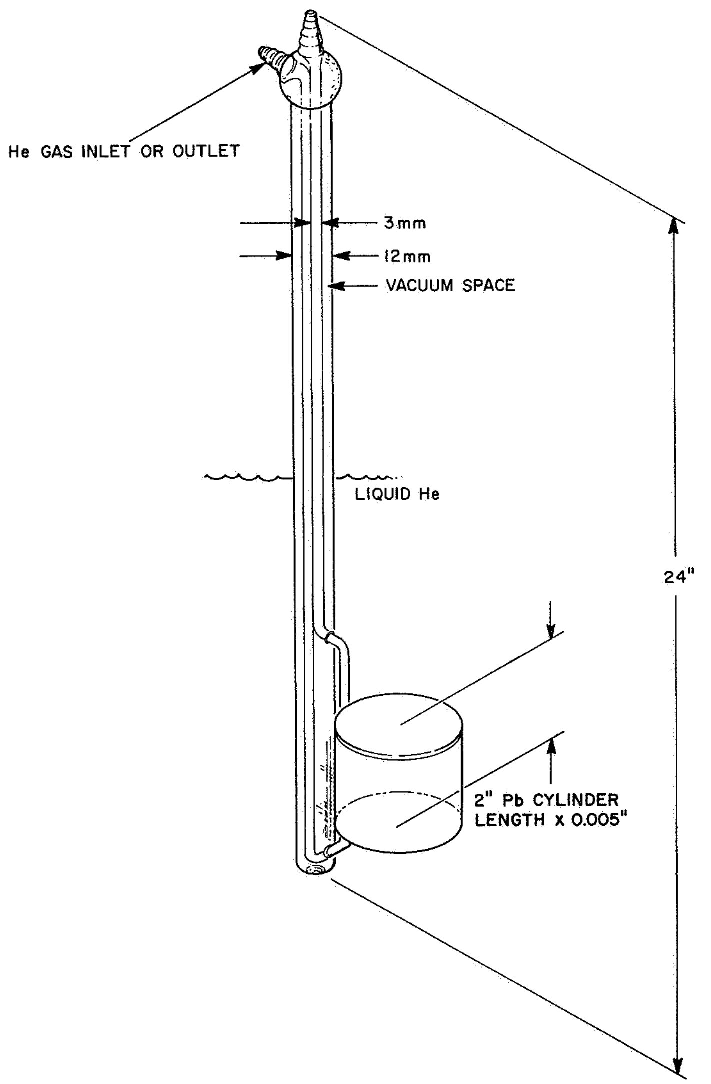
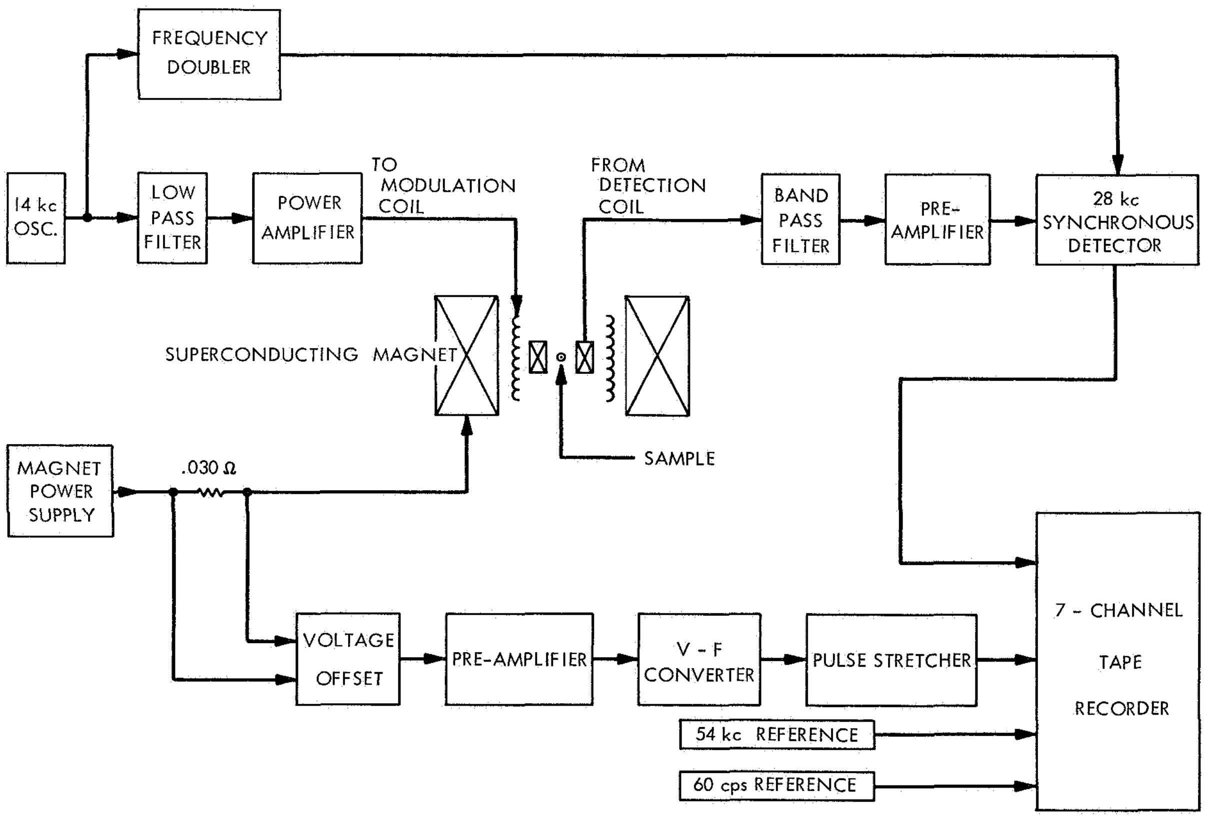
8. D. D. Elleman, C. D. Pearce, S. L. Manatt, Magnetic Resonance Studies of Soils and Rocks I A Preliminary Proton NMR Study JPL SPS 37-34, Vol. IV.

LOW-TEMPERATURE PHYSICS



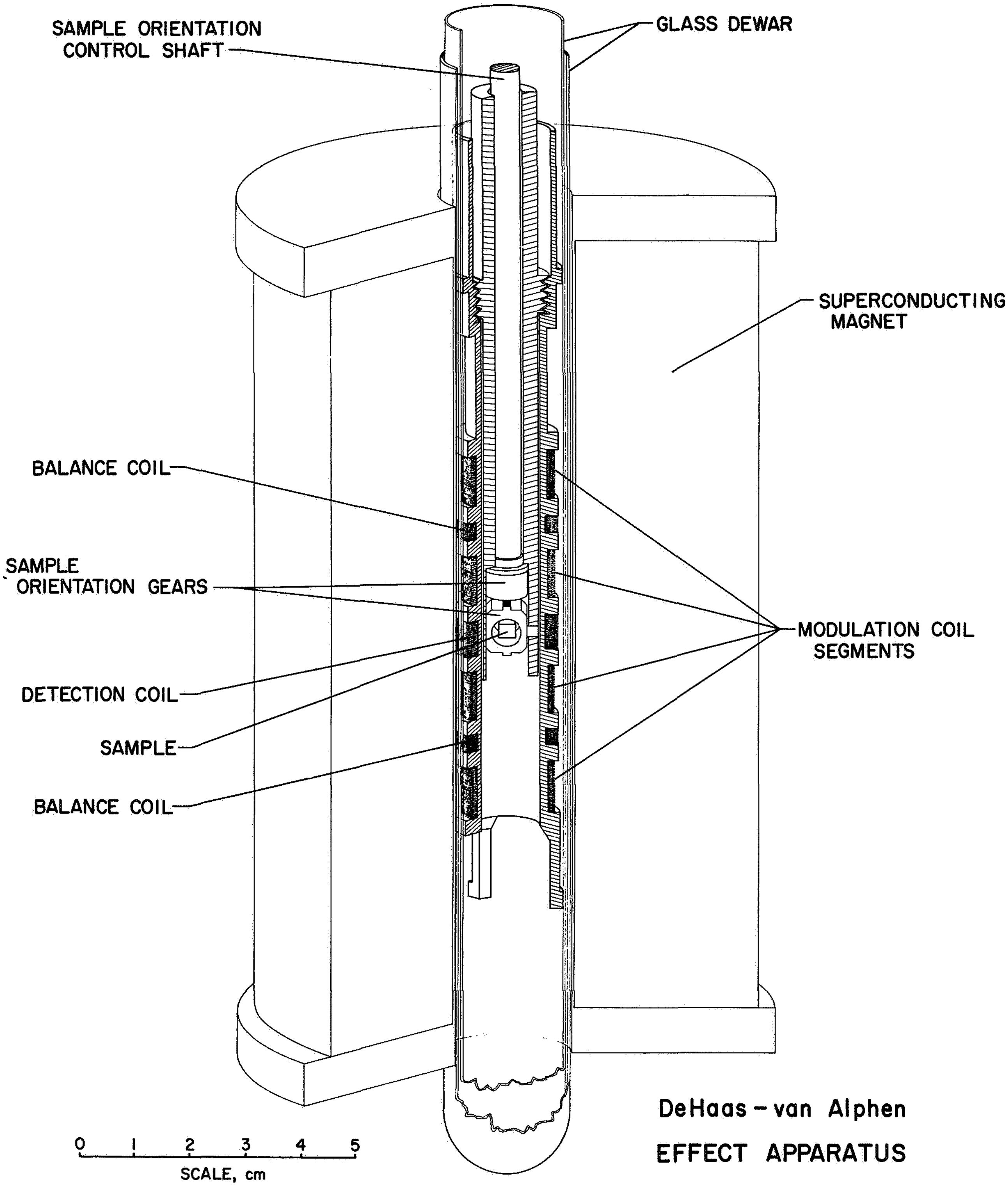
HELIUM GAS SUPERCONDUCTOR SWITCH
(PYREX GLASS)

LOW-TEMPERATURE PHYSICS



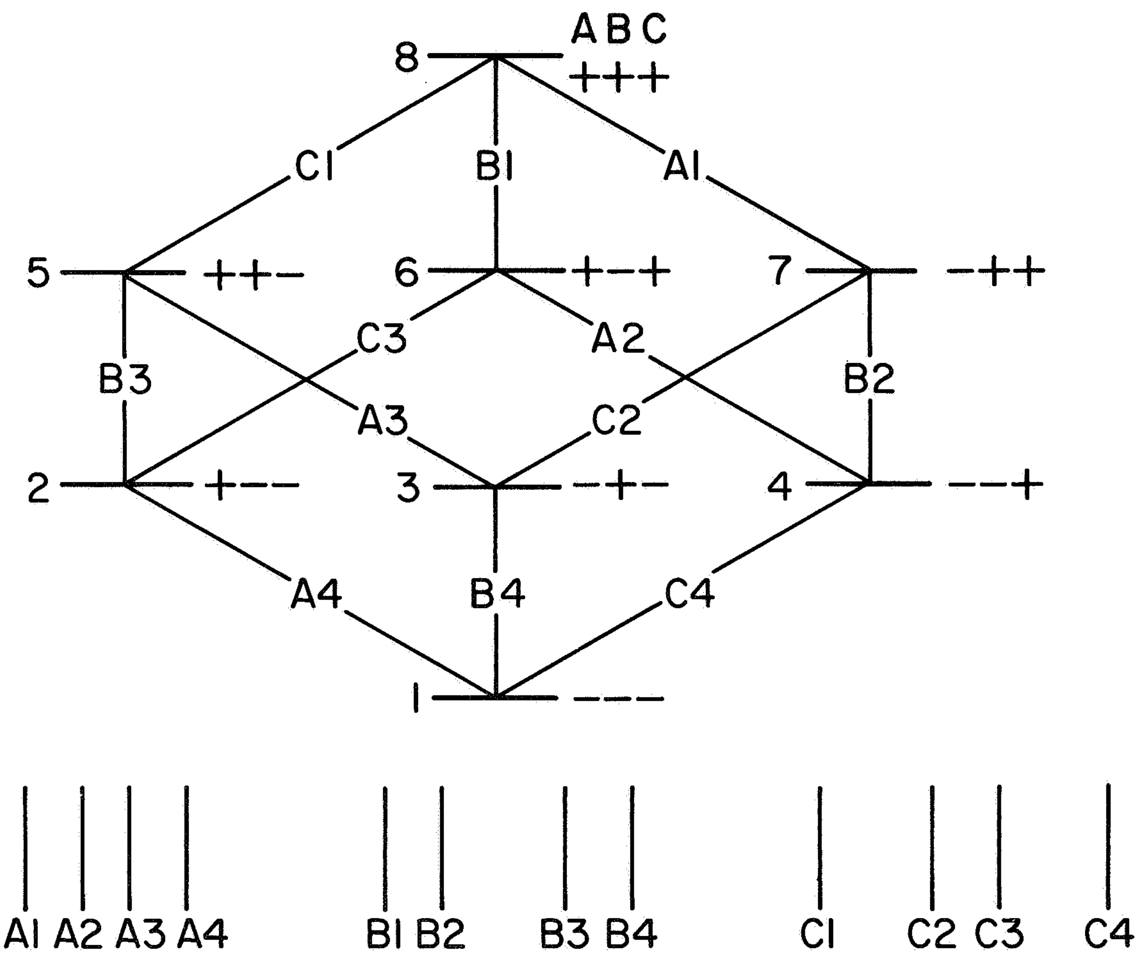
DeHaas-van Alphen EFFECT DATA ACQUISITION SYSTEM

LOW-TEMPERATURE PHYSICS



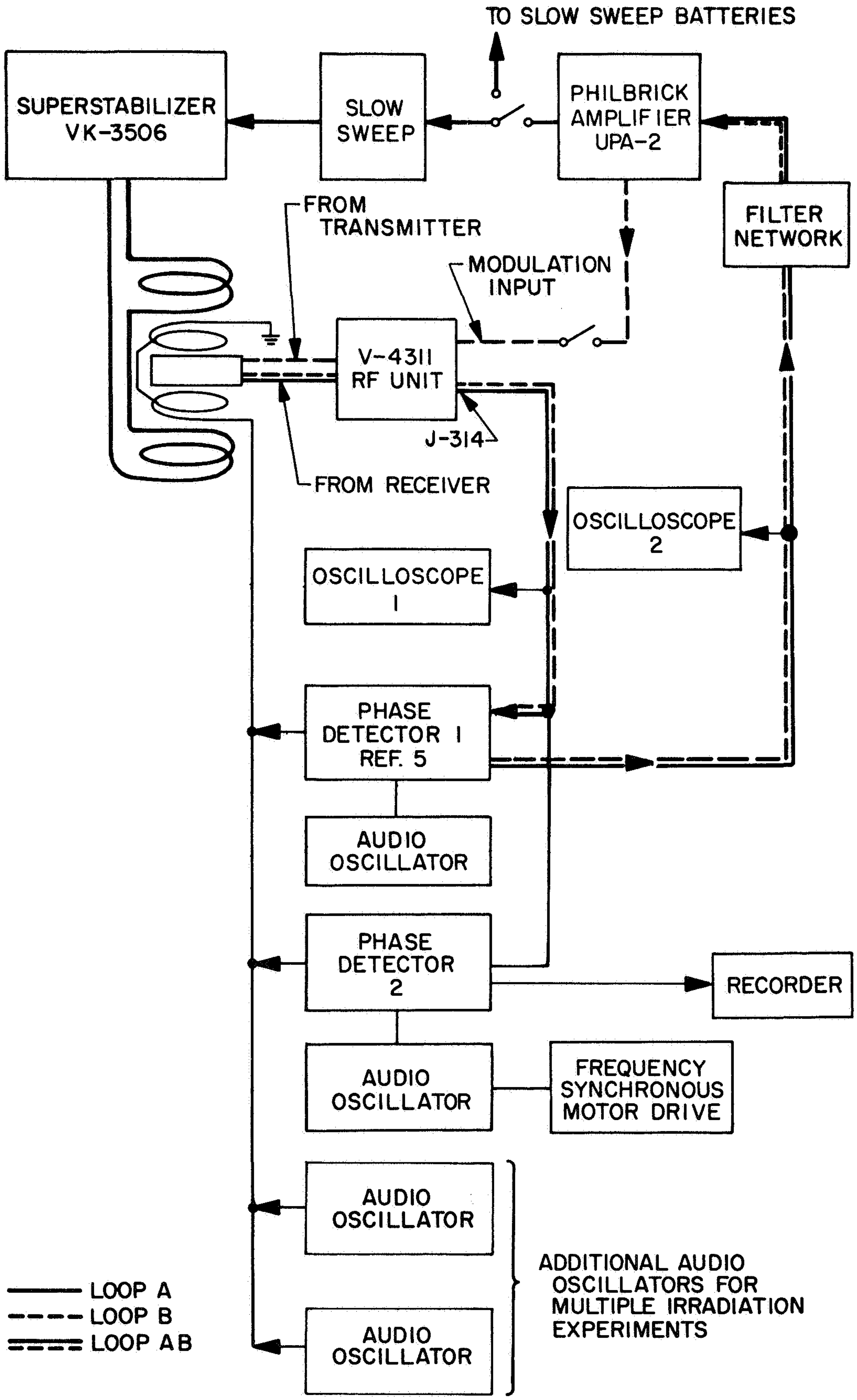
De Haas-van Alphen EFFECT APPARATUS

LOW-TEMPERATURE PHYSICS



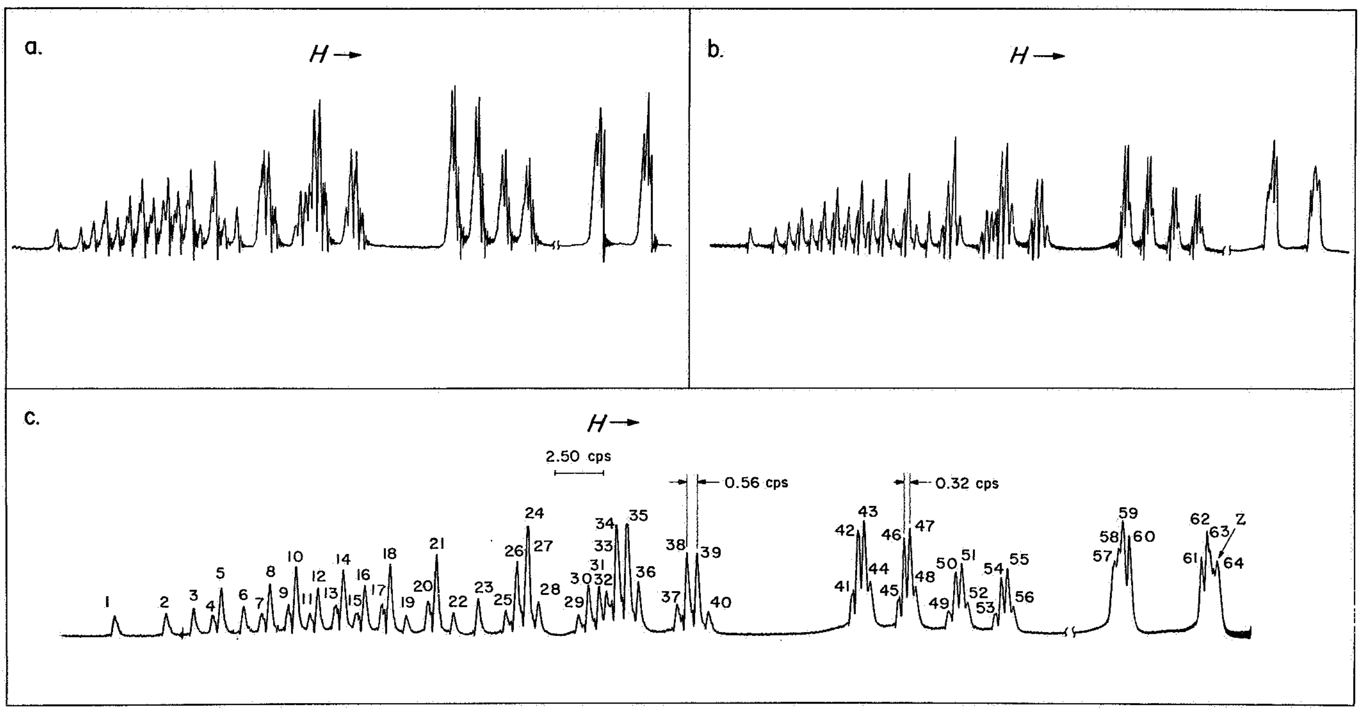
SCHEMATIC ENERGY-LEVEL DIAGRAM AND SPECTRUM FOR A SYSTEM OF THREE WEAKLY COUPLED SPIN 1/2 NUCLEI (ABC). THE MAGNETIC MOMENTS ARE ASSUMED POSITIVE AND THE STEADY FIELD IS ALONG THE $-z$ DIRECTION. FOR ALL COUPLINGS OF POSITIVE SIGN, THE SPECTRAL LINES DESIGNATED BY A1 - C4 BELONG TO THE TRANSITIONS GIVEN THE CORRESPONDING LABELS IN THE LEVEL DIAGRAM. THE TRANSITIONS OF A AND C FORM TWO PARALLELOGRAMS IN THE LEVEL SCHEME (A1C1A3C2 AND A2C3A4C4, RESPECTIVELY). A CHANGE IN THE SIGN OF J_{AC} LEADS TO A REASSIGNMENT OF THE A AND C LINES ON OPPOSITE SIDES OF THESE PARALLELOGRAMS. THUS A1 IS EXCHANGED FOR A3, ETC. STRONG IRRADIATION OF LINES B1 AND B2 WILL LEAD TO AN A-SPECTRUM IN WHICH THE LEVELS 6 AND 8 HAVE EFFECTIVELY COLLAPSED AS HAVE THE LEVELS 4 AND 7. THUS THE RESULTS OF DOUBLE IRRADIATION EXPERIMENTS MAY BE PREDICTED FROM THE LEVEL DIAGRAM FOR THE APPROPRIATE SET OF RELATIVE SIGNS.

LOW-TEMPERATURE PHYSICS



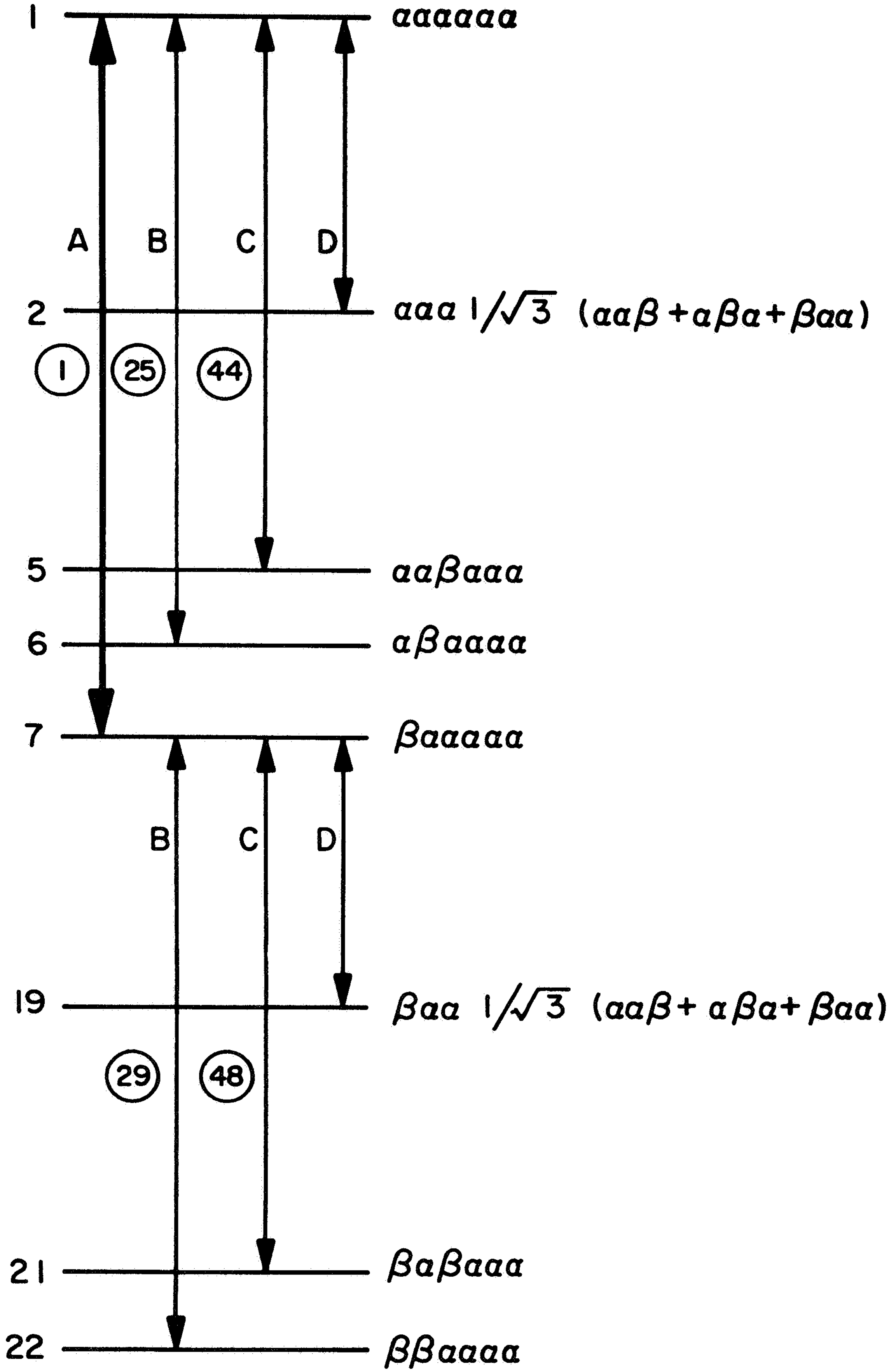
BLOCK DIAGRAM OF FREQUENCY LOCK SPECTROMETER

LOW TEMPERATURE PHYSICS



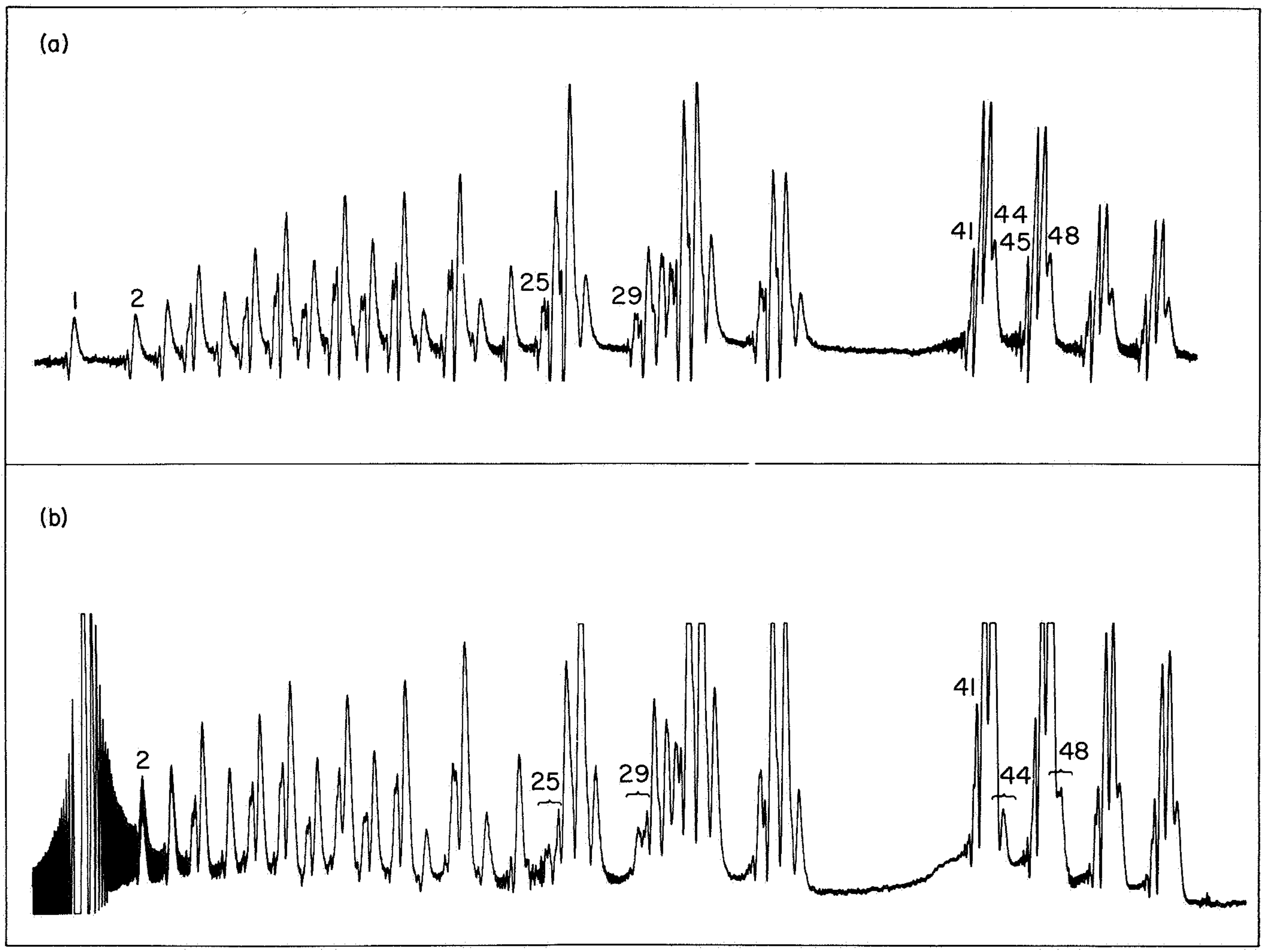
NMR SPECTRA

LOW-TEMPERATURE PHYSICS



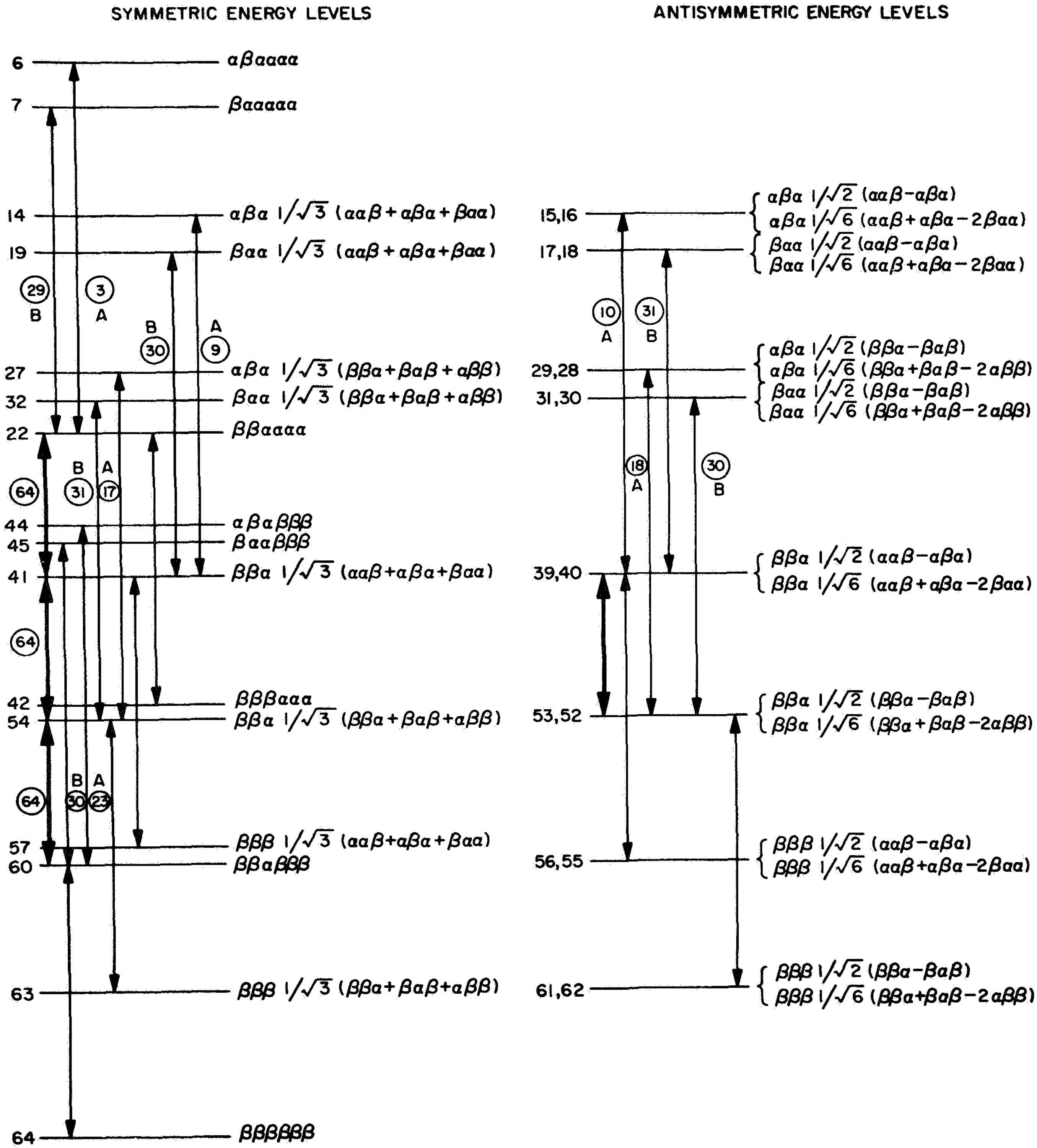
ENERGY-LEVEL DIAGRAM

LOW-TEMPERATURE PHYSICS



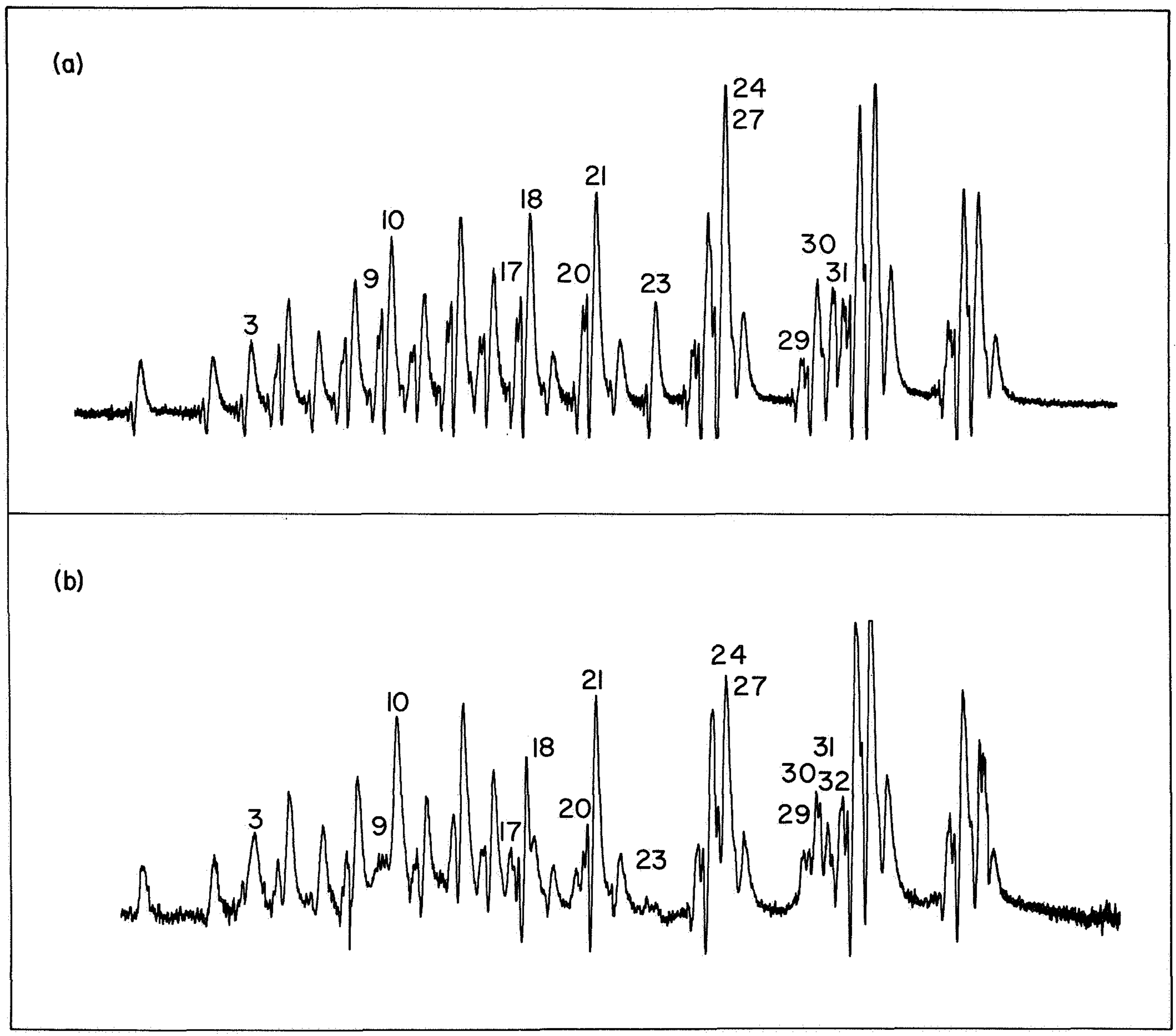
NMR SPECTRA

LOW-TEMPERATURE PHYSICS



ENERGY-LEVEL DIAGRAM

LOW-TEMPERATURE PHYSICS



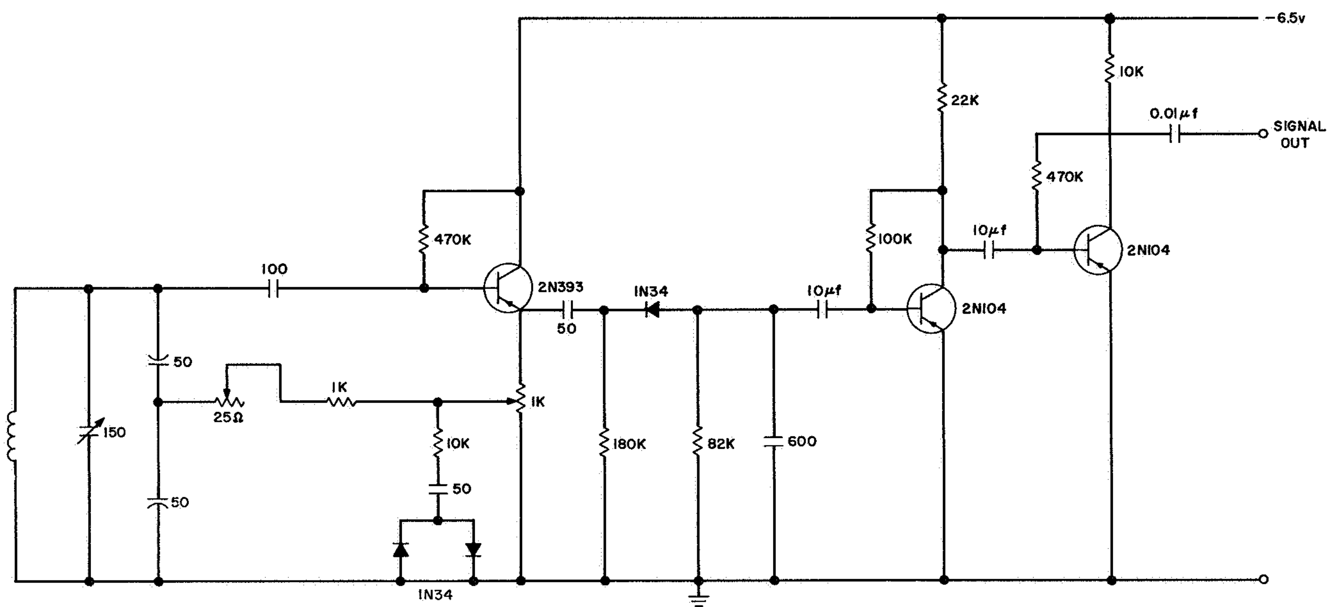
NMR SPECTRA

LOW-TEMPERATURE PHYSICS

SOIL SAMPLE DATA

SAMPLE	AREA MEASURED	CORRECTED AREA	DENSITY, g/cc	WEIGHT % ^1H	GRAVIMETRIC AIR DRY WEIGHT % H_2O	WEIGHT % H_2O
BLANK	-36	0	-	-	-	-
GUNFLINT CHERT	-32	4	1.3 (CHIPPED ROCK)	0.021	-	0.19
CALIBRATION SAMPLE OF 1% $(C_6H_{12}O_6)_n$ GLASS BEADS		15	1.5	0.067		0.60
69 - 1 - WET	213	249	1.3	1.3	3.8	12.0
69 - 1 - DRY	158	194		1.0		9.0
17 - WET	215	251	1.0	1.7	2.0	15.2
17 - DRY	50	86		0.58		5.2
2 - 1 - WET	9	45	1.6	0.19	0.3	1.7
2 - 1 - DRY	-7	29		0.12		1.1

LOW-TEMPERATURE PHYSICS



SAMPLE COIL

Title THEORETICAL PHYSICS

NASA PROGRAM	SCIENCE TASK LEADER	DIRECTED TOWARD WHICH FLIGHT PROGRAM?
129	F. B. Estabrook	

BUDGET (K) | NASA Code: 129-02-07-01-55 | JPL Job. No. 329-20901-1-3280

	E	T	Total	Salary	Proc.	Total Direct	Total Green
FY '65	7.2	--	7.2	106	12	118	262
FY '66	6.0	--	6.0	87	37	124	260

Total FY '66 Commitments to 1 September 1965 40

OBJECTIVE:

To increase theoretical understanding at the forefront of modern physics. Experience shows that applications in many fields, many of them unforeseen, appear quite regularly in the course of the work. Current areas of interest: (a) Interaction of High-Intensity Radiation with Matter, (b) Plasma Physics, (c) Relativity, (d) Elementary Particles, (e) Many-Body Problem.

ABSTRACT:

(a) M. M. Saffren

Current work is on the interaction with matter of correlated many-photon states of the electromagnetic field. Our method of calculation differs from others in that we do not use the so-called Volkoff Solution of the electron wave equation, but rather use invariant perturbation theory as expressed by Feynman diagrams. Compton scattering of an electron in an intense uncorrelated beam was first considered; the S-matrix for an electron scattered by a correlated many-photon state has now been set up, and calculations are under way.

(b) and (e) C.-S. Wu and E. H. Klevans

The research program in theoretical plasma physics has concentrated on the study of certain important transport phenomena, for example, the temperature relaxation of a non-isothermal plasma, and the high-frequency conductivity of a plasma in quasi-equilibrium.

(c) F. B. Estabrook and H. D. Wahlquist

The research in general relativity and gravitation has resulted in a new formulation of general relativity, which avoids many of the algebraic difficulties inherent in the customary covariant terminology, and so enables exact solution of a number of heretofore unsolved problems. A first application has now been made, in a thorough discussion of rigid reference frames in Einstein space-times.

(d) J. S. Zmuidzinas

A general theory of particle symmetries has been proposed and is now being developed in several directions. A new and simple approach to the isolation of invariant scattering amplitudes has been found which will be applied in future calculations.

RECENT PUBLICATIONS AND PRESENTATIONS BY THE THEORETICAL GROUP

1. C.-S. Wu, E. H. Klevans, and J. R. Primack, Temperature Relaxation in a Fully Ionized Plasma, Phys. Fluids, 8, 1126 (1965).

2. C.-S. Wu, High-Frequency Conductivity of a Plasma in Quasi-Equilibrium, I. Formulation of a General Theory, Phys. Rev. 138, A51 (1965).

3. C.-S. Wu, High-Frequency Conductivity of a Plasma in Quasi-Equilibrium, II. Effect of a Uniform Magnetic Field, Phys. Rev. (1965).

4. E. H. Klevans, C.-S. Wu and J. R. Primack, High-Frequency Conductivity Calculations Using the Plasma Kinetic Equation, to appear in the Proceedings of the 7th International Conference on Phenomena in Ionized Gases, Belgrade (1965). Paper presented by E. H. Klevans.

5. E. H. Klevans and J. R. Primack, Collision-Induced High Frequency Instability in a Fully Ionized Plasma, to appear in the Proceedings of the 7th International Conference on Phenomena in Ionized Gases, Belgrade (1965). Paper presented by E. H. Klevans.

6. C.-S. Wu, Kinetic Equation for an Inhomogeneous Plasma in a Uniform External Magnetic Field, to appear in the Proceedings of the 7th International Conference on Phenomena in Ionized Gases, Belgrade (1965).

7. C.-S. Wu, Invited Lectures in Plasma Kinetic Theory, Summer Institute of Science, Taiwan (sponsored by Academia Sinica, National Taiwan University and National Tsing-Hua University). July 1 - August 25, 1965.

8. J. S. Zmuidzinas, Unitary Representations of the Lorentz Group on Four-Vector Manifolds, submitted to J. Math. Phys.

9. J. S. Zmuidzinas, Unitary Representations of the Lorentz Group on Four-Vector Manifolds, Bull. Am. Phys. Soc. 10, No. 6, 712 (1965).

10. J. S. Zmuidzinas, Particle Symmetries, JPL Report No. 32-797, Aug. 1, 1965. In press.

11. J. S. Zmuidzinas, Construction of Invariant Scattering Amplitudes. Paper submitted to Chicago meeting, Am. Phys. Soc. 28-30, October, 1965.

12. M. M. Saffren, The Rotating Superconductor, Part I: The Fluxoid, Part II: The Free Energy, Part III: The Superelectrons as an Incompressible Charged Fluid, JPL TR 32-650 (I, II, and III), March 15, May 14, May 31, 1965.

13. A. F. Hildebrandt and M. M. Saffren, Superconducting Transition of a Rotating Superconductor — The Hollow Cylinder. Proc. of Ninth Int. Low Temperature Conf., Columbus, Ohio, 1964. In press.

14. M. M. Saffren, English translation of The Momentum of Sound Quanta I, G. Sussmann, Z. f. Naturforschung, 11a, 1-14 (1956). JPL TR 32-812, in press.

15. F. B. Estabrook and H. D. Wahlquist, Dyadic Analysis of Space-Time Congruences, J. Math. Phys. 5, 1629-44 (Nov. 1964).

16. H. D. Wahlquist and F. B. Estabrook, Rigid Motions in Einstein Spaces, ms. 86 pages, submitted to J. Math. Phys.

17. F. B. Estabrook, Measurement of Gravitational and Inertial Fields in General Relativity; paper presented to the International Conference on General Relativity and Gravitation, London, July 1-10, 1965.

18. H. D. Wahlquist, Rigid Motions in Einstein Spaces, paper presented to the International Conference on General Relativity and Gravitation, London, July 1-10, 1965.

19. E. H. Klevans and J. R. Primack, Study of the Dielectric Constant in Related Problems for a Two-Temperature Plasma, to be published.

RECENT THEORETICAL GROUP PROGRESS REPORTS IN JPL SPACE PROGRAM SUMMARIES

C.-S. Wu, High Frequency Conductivity of a Plasma in Quasi-Equilibrium, SPS 37-31, Vol. IV, Jan. 30, 1965.

M. M. Saffren, London's Equation as an Expression of Larmor's Theorem, SPS 37-31, Vol. IV, Jan. 30, 1965.

O. von Roos, Remarks on the Frequency Shift in High Intensity Compton Scattering, SPS 37-31, Vol. IV, Jan. 30, 1965.

M. M. Saffren, Space-Time Symmetry and Mass Splitting, SPS 37-32, Vol. IV, April 30, 1965.

H. D. Wahlquist and F. B. Estabrook, Rigid Motions in Einstein Space, SPS 37-32, Vol. IV, April 30, 1965.

O. von Roos, Theory of Ionization of Atomic Systems by High Intensity Radiation, SPS 37-33, Vol. IV, June 30, 1965.

M. M. Saffren, Interaction of Intense Electromagnetic Beams With Electron Beams, SPS 37-33, Vol. IV, June 30, 1965.

F. B. Estabrook and H. D. Wahlquist, Relativistic Rigid Frames in Gravitational Fields, SPS 37-35, Vol. IV. In press.

J. S. Zmuidzinas, Construction of Invariant Scattering Amplitudes, SPS 37-35, Vol. IV. In press.

Title NUCLEAR PHYSICS RESEARCH

NASA PROGRAM	SCIENCE TASK LEADER	DIRECTED TOWARD WHICH FLIGHT PROGRAM?
129	A. Bruce Whitehead	

BUDGET (K) | NASA Code: 129-02-03-08-55 | JPL Job. No. 329-21701-1-3280

	E	T	Total	Salary	Proc.	Total Direct	Total Green
FY '65	1.8	0.9	2.7	34	92	126	172
FY '66	2.0	2.0	4.0	44	129	173	241

Total FY '66 Commitments to 1 September 1965 28

OBJECTIVE:

To conduct experimental research in selected problems of nuclear physics and the physics of heavy-ion interaction with matter. Problems are selected for their intrinsic physical interest, for the particular applicability of the results to technology important to NASA, and for their challenge to the unique capabilities of the present personnel and apparatus. The goal of current experiments concerns: (a) the specific energy loss of fission fragments in various stopping media, (b) the yield and energy spectrum of secondary electrons accompanying fission, (c) current topics in fission physics.

ABSTRACT:

The research facilities in the Nuclear Physics laboratory are centered around a Dynamitron accelerator. A variety of basic electronics and hardware is available for the experiments which are being planned, and a four-parameter data acquisition system has been obtained on lease. The following experiments are either being performed or in an advanced stage of planning.

1. The neutron yield and spectrum which can be obtained using the accelerator will be measured. Neutrons will be produced as a deuteron beam strikes a thick beryllium target. We estimate the neutron flux to be 1 or 2 $\times 10^{12}$ neutrons per second. The fast neutron flux from this reaction will also be moderated in a water tank to provide a high flux of thermal neutrons for most of the fission experiments.

2. An experiment to measure the specific energy loss of fission fragments in matter has been designed, and most of the components are being tested. In this experiment fission fragments traverse a thin foil of the material under study. The velocity of the fragment before and after traversing this foil is measured by a time of flight technique, and the final energy is measured with a solid state detector. In principle the system can be calibrated to give a mass resolution of almost one mass unit and an energy resolution of better than 1 Mev. This experiment will provide a complete spectrum of fragment masses and energies concurrently. This experiment should provide not only the smooth dependence of the stopping cross-section with the Z of the fragment, but also any local fluctuations in the stopping cross-section in the vicinity of closed-shell atoms.

3. A simple lens experiment has been performed both to develop the techniques which will be used in the double velocity experiment referred to previously and to learn more about the physics of secondary electron emission produced by energetic heavy ions.

4. An electrostatic spectrometer has been designed to study the secondary electron energy spectrum in careful detail.

5. Considerable effort has been devoted to the theoretical aspects of the stopping process, both to understand the behavior and limitations of solid state detectors in detecting energetic heavy ions and to develop the thoretical background for the energy loss experiments. This is also in keeping with JPL's general interest in detector technology.

The following achievements over the past six months are considered significant:

1. The simple lens experiment has been performed and demonstrates the usefulness of the technique. The following results will be reported in a paper to be given to the IEEE at a conference later this month.

   a. A curve is given which is interpreted as the probability of a given number of secondary electrons being emitted when a fission fragment traverses a thin nickel foil.

   b. The response of a gold silicon surface barrier detector to very low energy electrons is given. The detector exhibits a pulse height defect which can be attributed to the energy loss by the electron in passing through the surface gold layer.

   c. Using a suitably biased grid and observing the median of the number of electrons emitted per fragment, a curve has been obtained which gives some indication of the energy spectrum of the secondary electrons. This integral bias curve has been fitted to a simple power law $N(V) = N_1 V^{-0.29}$. In order to obtain a differential energy spectrum, it is necessary to make some assumption about the angular distribution of these electrons. If the distribution is isotropic or if the angular distribution is not energy dependent, then it may be shown that the differential spectrum is given by the relation $n(\epsilon) = \text{const } \epsilon^{-1.29}$. This does not fit a Maxwell Boltzman distribution; thus suggesting that the process is not one of thermal equilibrium and evaporation in a small volume of the foil (thermal spike model). An analysis of the distribution as reflecting the Coulomb scattering of these electrons becomes complicated by the strong angular dependence of this process. It is hoped that the forthcoming electron spectrometer experiment will provide data over a larger energy range than is possible with the lens.

2. Solid state detectors exhibit a large pulse ehgith defect and energy dispersion when detecting heavy ions. The contribution of the atomic scattering process to this defect and dispersion has been computed. The secondary process of a recoiling detector atom causing further electron-hole pair formation was included in the treatment.

The general problem was reduced to dimensionless terms using a method derived by Lindhard et al. Thus, it was possible to obtain a single curve to relate the dimensionless energy defect to the ion dimensionless energy and a second such curve for dispersion. Comparing the results of the computation with experimental data available in the literature shows good agreement, indicating that atomic scattering accounts for most of the observed pulse height defect over a wide range of Z and energy. Data for detector resolution are available only over a limited portion of the predicted curve, and suggest that some process other than atomic scattering is contributing to the dispersion. These results are to be published shortly.

The current status of the work in the laboratory is as follows:

1. The Dynamitron has been operated at a current in excess of 2 milliamps up to 2.5 Mev. Problems with the beam tube and the ion source have delayed the acceptance of the accelerator from the contractor, but we anticipate that this will be accomplished shortly.

2. Design and testing of the electron lens which will be used in the time of flight experiments is almost complete. Additional refinements in the associated electronics will be required before the time of flight experiment is ready.

3. The electrostatic spectrometer has been designed and constructed. It is presently being tested in a magnetic-field-free enclosure. Additional development is required on the electron detector which is associated with the spectrometer. An electronics system for sweeping the field of the spectrometer is complete.

Plans for the next six-month period include making the neutron flux measurements and setting up the specific-energy-loss experiment. The latter should provide a large amount of data which can be analyzed while the Dynamitron laboratory is being moved to its permanent site next spring. Also during this period an analyzing magnet will be obtained and installed.

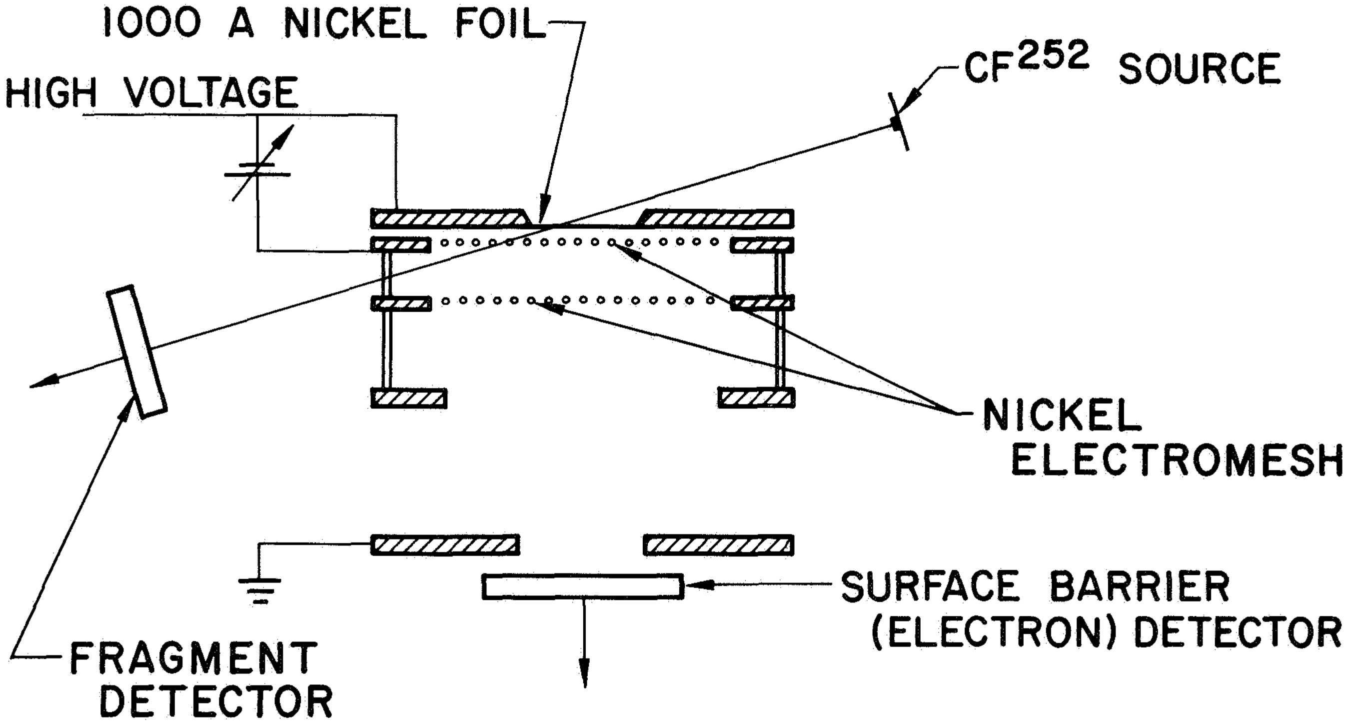
PUBLICATIONS AND REPORTS

1. A. Bruce Whitehead "Yield and Energy Spectrum of Secondary Electrons Generated by Fission Fragments," to be presented at the 12th Nuclear Science Symposium, Institute of Electrical and Electronic Engineers, San Francisco, October 18-20, 1965.
2. Eldon L. Haines and A. Bruce Whitehead, "Resolution of Semiconductors for Fission Fragments," Rev. Sci. Instr. 36, 1385 (1965).
3. Eldon L. Haines and A. Bruce Whitehead, "Pulse-Height Defect and Energy Dispersion in Semiconductor Detectors," submitted for publication to Review of Scientific Instruments.
4. Eldon L. Haines and A. Bruce Whitehead, "Pulse-Height Defect and Energy Dispersion in Semiconductor Detectors," JPL SPS 37-35, Vol. IV.

NUCLEAR PHYSICS RESEARCH

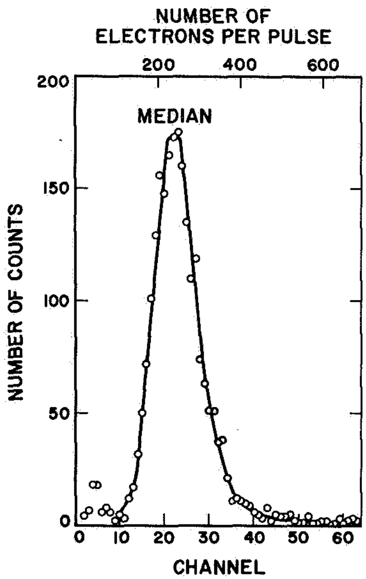
DYNAMITRON ACCELERATOR

NUCLEAR PHYSICS RESEARCH

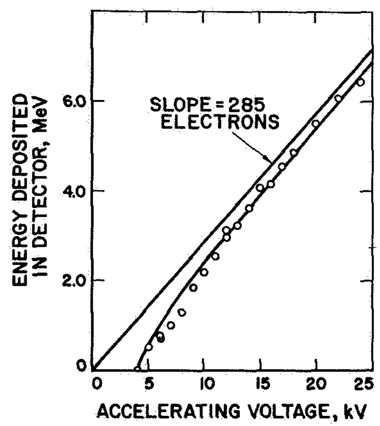


APPARATUS FOR LENS EXPERIMENT

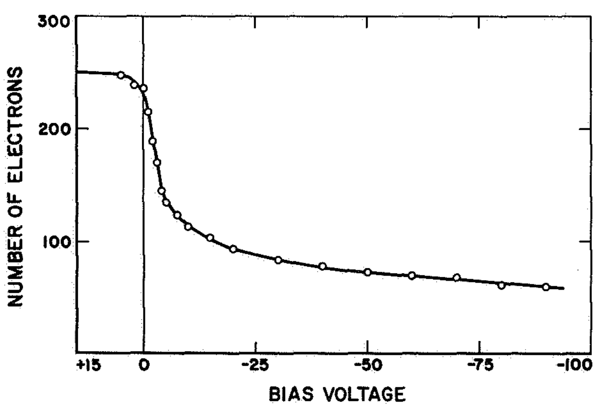
NUCLEAR PHYSICS RESEARCH



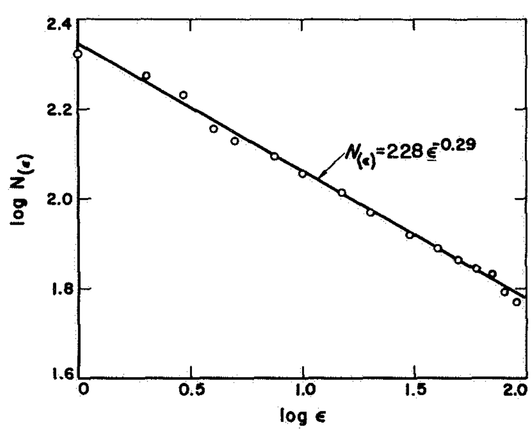
SECONDARY ELECTRON
YIELD



ELECTRON DETECTOR
CALIBRATION

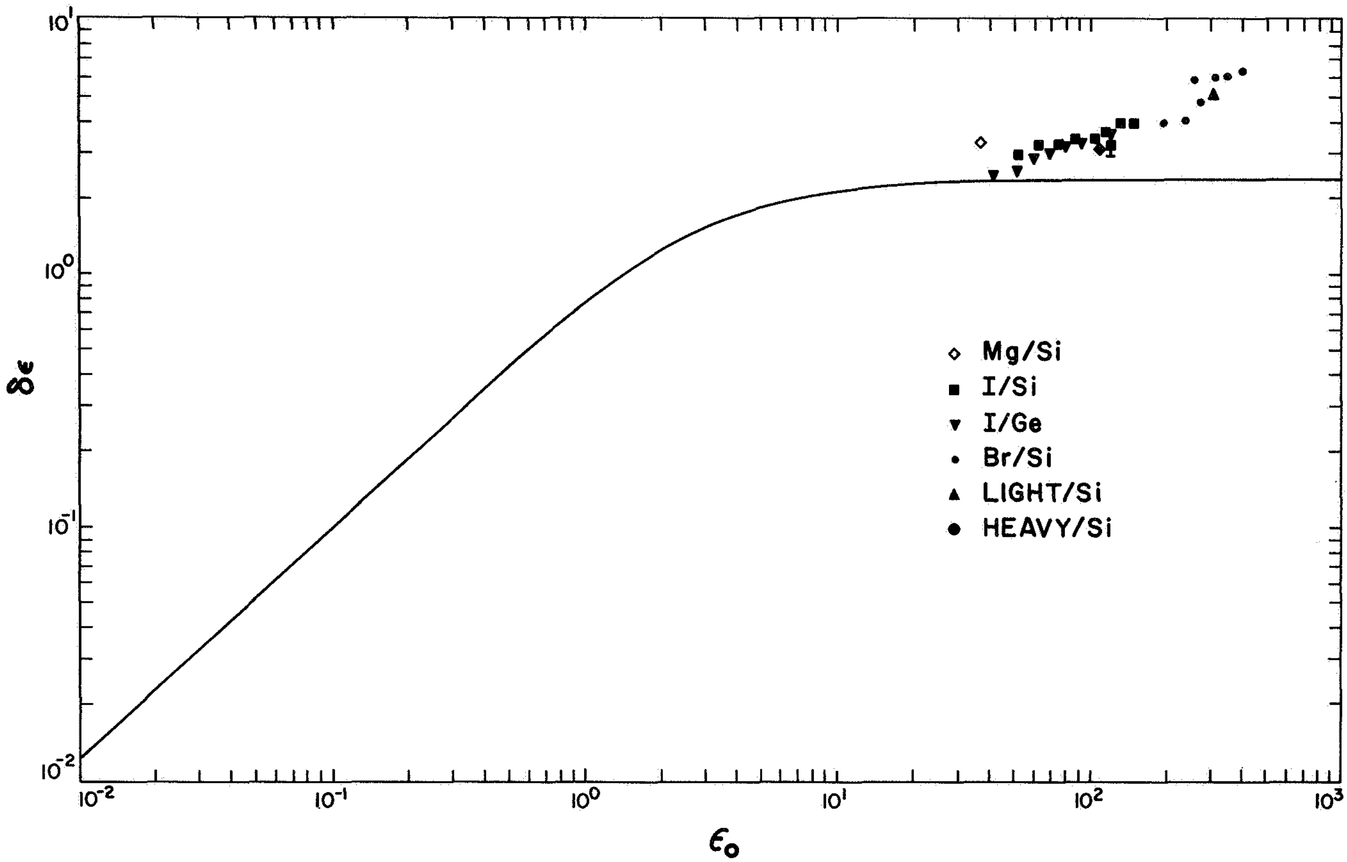


INTEGRAL BIAS CURVE—LINEAR



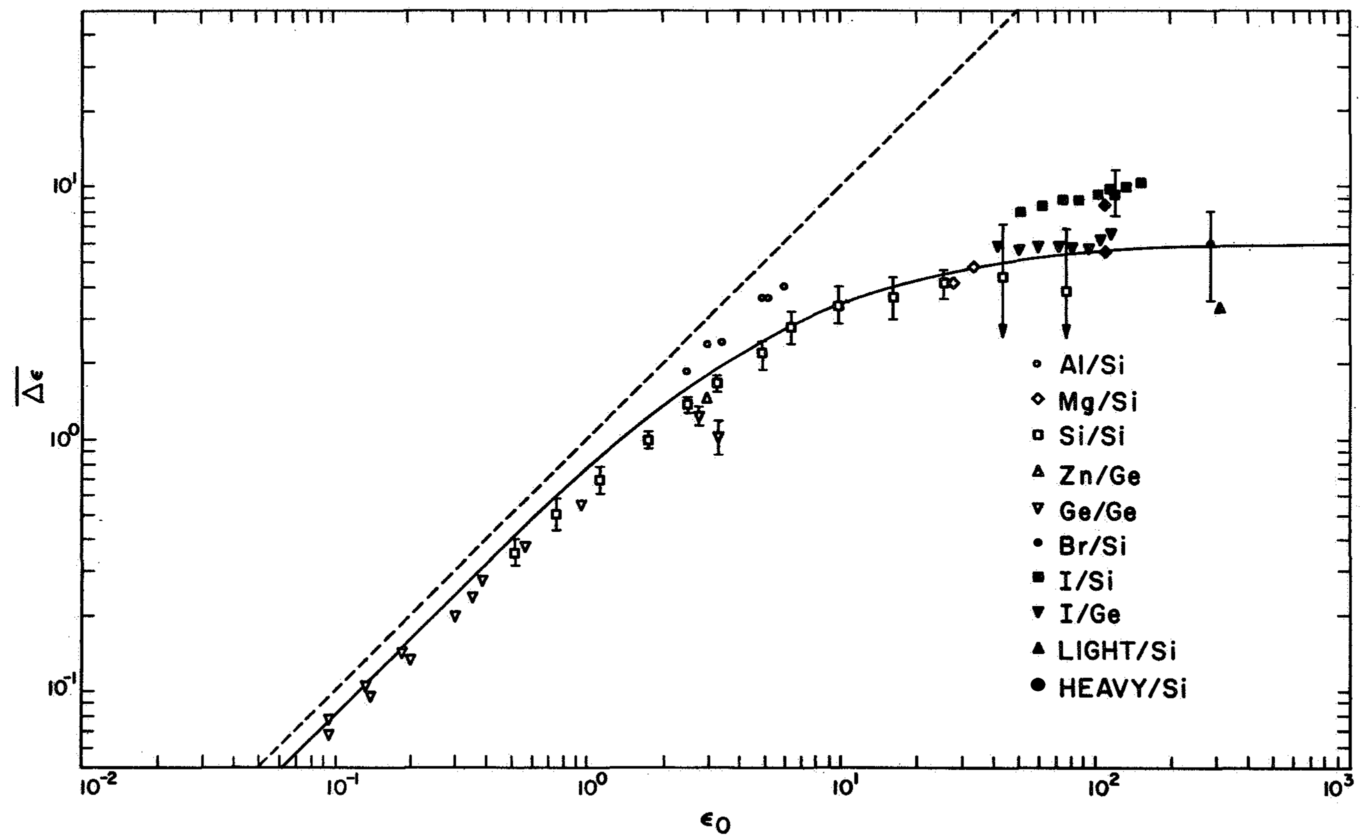
INTEGRAL BIAS CURVE—LOGARITHMIC

NUCLEAR PHYSICS RESEARCH



DIMENSIONLESS ENERGY DISPERSION $\delta\epsilon$
PLOTTED AS A FUNCTION OF ION ENERGY ϵ_0

NUCLEAR PHYSICS RESEARCH



DIMENSIONLESS PULSE-HEIGHT DEFECT $\overline{\Delta\epsilon}$
PLOTTED AS A FUNCTION OF ION ENERGY ϵ_0

Title Organic Chemistry

NASA PROGRAM	SCIENCE TASK LEADER	DIRECTED TOWARD WHICH FLIGHT PROGRAM?
129	S. L. Manatt	

BUDGET (K) | NASA Code: 129-03-11-06 | JPL Job. No. 329-31501

	E	T	Total	Salary	Proc.	Total Direct	Total Green
FY '65	2	0	2	26	20	46	82
FY '66	2	.2	2.2	25	62	87	126

Total FY '66 Commitments to 1 September 1965 38

OBJECTIVE:

To maintain a high level of competence in modern techniques of chemistry capable of contributing to studies of electronic structures of molecules, solution of analytical chemistry problems, conception of space chemistry experiments, organic and inorganic syntheses of model compounds, development of new materials, study of kinetics of reactions, development of instrumentation, determination of structures of polymers, data processing of experimental results and theoretical calculations of molecular properties; major emphasis on development of nuclear magnetic resonance (NMR) instrumentation and applications of NMR to problems of chemical and physical interest.

ABSTRACT:

The work in progress under this task can be divided into four principle areas as indicated below.

A. High-Resolution NMR Studies. - This work is primarily concerned with the determination of the magnitudes and relative signs of NMR spin-spin coupling constants and the relation of these parameters to molecular structure. We have accomplished complete analyses of a number of complex NMR spectra using NMR multiple resonance techniques and computer analyses; among the molecules we have studied are propylene

oxide, indene oxide, styrene sulfide, styrene imine, cyclopentadiene, cyclohexadiene, methylphosphine, dimethylphosphine, triethylphosphine and isopropenylacetylene. We have begun the analyses of the complex NMR spectra of the following: 1,1-difluoro-2-methylbutadiene, 1,2-dihydronaphthalene, perfluoro-1-butene, 4-H-heptafluoro-1-butene, cyclohexene, cyclopentene, a series of organic isonitriles, a number of trifluorovinyl derivatives and heptafluoropropyl derivatives, and a number of substituted styrenes.

B. Organic Chemistry. - A number of substances have been or are being synthesized for NMR studies, physical and chemical studies, and as monomers for preparation of polymers; these include the isomeric 1,4-difluorobutadienes, a number of trifluoroacetyl derivatives of alcohols, phenols and amines, vinylcyclopropane, cyclopropylethylene oxide, trimethylsilanoethylene oxide, triethylphosphine, triethylphosphine oxide, tetraethylphosphonium salts, some halogen substituted fluoroethanes and ethylenes, and some polyether polymers. Theoretical studies are in progress on small ring organic compounds, nitrogen heterocyclics and other extended π-electron systems.

C. Instrumentation. - We have carried out a study which suggests that it is feasible to consider using wide-line NMR as a Voyager or lunar soft-landing experiment to gather data on the nature of soils and rocks and amount of protons present in Martian or lunar surface or subsurface. A small, simple wide-line NMR spectrometer for protons has been constructed and successfully tested. We have discovered that a sample external to a NMR receiver coil can be used to control a NMR spectrometer and with this technique have begun studies of the NMR spectra of a number of ^{14}N, ^{13}C, ^{11}B and ^{31}P containing molecules. We recently received a Varian C-1024 time averaging computer which is being integrated into our spectrometer. We have built a linear sweep unit for our field-lock HR-60 spectrometer.

D. Analytical Chemistry. - We continue to provide availability of NMR instrumentation, analyses and interpretation for various research and flight programs on the Laboratory. During the past year we have performed NMR analyses of a number of elastomer and potting compounds to determine their chemical structure and purity, demonstrated feasibility of analyzing by NMR for H_2O in liquid N_2O_4 faster and more accurately than other methods, performed NMR analyses of vinyl monomers and polymers and interaction of $LiClO_4$ with polyethers for Polymer Research Section (382), worked out gas chromatographic separation of CF_4 and N_2O, studied by NMR the reaction between methanol and 100% nitric acid for Liquid Propulsion Section(384), developed NMR analytical procedure for quality control of "alrosperse" for Solid Rocket Section (381), studied broad-line NMR of soil and rock samples and showed proton contents as small as 0.05% can be measured, continued ^{19}F NMR studied of derivatives of poly(propylene oxide) which has lead to determination of stereochemistry of the polymer chains, and discovered that ^{19}F NMR spectra of trifluoroacetates provide an excellent classification scheme for hydroxyl groups.

Publications and Presentations for 1965

1. The Relative Signs of the Nuclear Spin Coupling Constants in Propylene Oxide and Indene Oxide, J. Chem. Phys., 42, 650 (1965).
2. The Relative Signs of the NMR Proton-Proton Coupling Constants in Styrene Sulfide and Styrene Imine, J. Am. Chem. Soc., 87, 2220 (1965).
3. Nitrogen Analogues of Sesquifulvalene. II. Theoretical Correlation of Ground-State Properties, J. Am. Chem. Soc., 87, 2901 (1965).
4. Nitrogen Analogues of Sesquifulvalene. III. Theoretical Correlation of Excited-State Properties, J. Am. Chem. Soc., 87, 2908 (1965).
5. The Rates of Some Degenerate Rearrangement as Determined by Nuclear Magnetic Resonance, J. Am. Chem. Soc., 87 (1965) in press.
6. Molecular Orbital Calculations. I. Some Cyclobutadiene Systems Joined With Two Cyclopropenyl, Cyclopentadienyl or Cyclohetatrienyl Rings, J. Am. Chem. Soc., (1965) in press.
7. Molecular Orbital Calculations. II. A Treatment of 1,3-π-Interaction in Cyclobutenyl Systems, J. Am. Chem. Soc., (1965) in press.
8. Utilization of a Control Sample External to a Nuclear Magnetic Resonance Receiver Insert, J. Am. Chem. Soc., (1965) in press.
9. NMR of Phosphorus Compounds. II. The Relative Signs of the Spin-Spin Couplings in Dimethylphosphine and Methylphosphine, J. Am. Chem. Soc., (1965), in press.
10. On Internal Field-Frequency Control Systems, 6th Experimental NMR Conference, Mellon Institute, Pittsburgh, February 25, 1965, invited paper.
11. Characterization of Hydroxyl Groups by NMR, Seminar to Central Research Department, Minnesota Mining and Mfg. Co., St. Paul, June 18, 1965, invited lecture.

12. Analyses of the NMR Spectra of the Vinyl Protons of Cyclopentadiene and Cyclohexadiene Using Spin Decoupling, 150th Meeting of the American Chemical Society, Atlantic City, New Jersey, September 15, 1965.

13. Molecular Structure and Configuration of Polymers. The ^{1}H and ^{19}F NMR Spectra of Poly(alkylene Oxide) Terminal Groups, 13th Canadian High Polymer Forum, Ottawa, September 22 (1965).